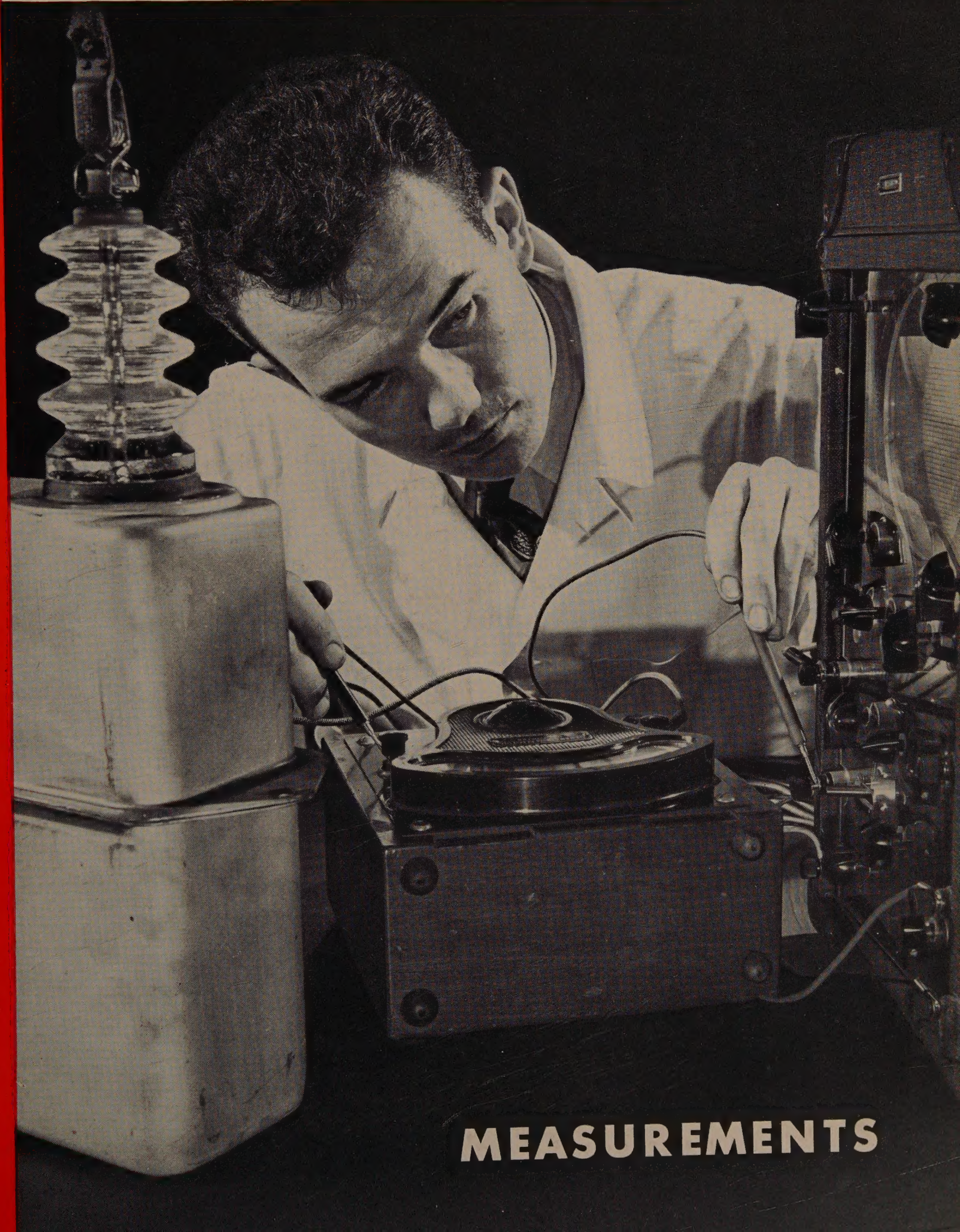
OLUME 52 NUMBER 10 . . . ONE YEAR FOUR DOLLARS

GENERAL ELECTRIC REVIEW

Illinois U Library

TABLE OF CONTENTS
Page Three



TOBER
949

MEASUREMENTS

Everyday measurements of mass can usually be most easily accomplished by mechanical means, such as a spring balance or torsion balance. For special situations, however, electrical measurement can often do what would otherwise be impossible. Take, for example, the mass spectrometer. With this instrument it is possible to measure molecular masses with such accuracy that mercury having mass 200 can be distinguished from its isotope having mass 201.

In many of the secondary fields of measurement such as temperature, sound, light and color, speed, stress and strain, vibration, magnetism, and others, electricity is pre-eminent. The thermocouple, utilizing as a measure of temperature the voltage generated by a pair of dissimilar metals in contact, has myriads of applications. Sound-level meters, employing the principle of the microphone, measure an almost incredible range of sounds. Color, one of the most intangible of all quantities, can be analyzed accurately by the recording spectrophotometer using a photoelectric tube to measure light reflectance. Electric tachometers measure speed of rotation in terms of the voltage from a generator connected to the rotating member. Strains in metallic parts of machinery or structures are measured with extreme accuracy through changes in the electrical resistance of a small wire cemented to the part under investigation. For the measurement of vibration, a transducer which converts mechanical energy into a voltage that is recorded by an oscillograph, performs an extremely useful service. Magnetization can be measured most satisfactorily by means of a test coil and a flux meter.

The list of electric instruments for measuring non-electrical quantities could be extended almost indefinitely. Many are well known and widely used. Others are of more limited application. In the aggregate, they permit an enormous extension of man's measuring ability in a wide variety of directions.

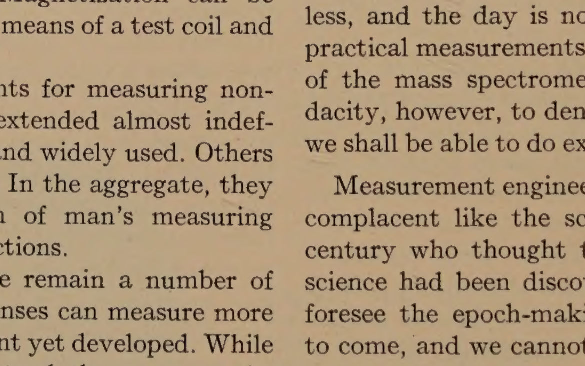
With all this, however, there remain a number of fields in which man's natural senses can measure more satisfactorily than any instrument yet developed. While electrical measurements can extend the range of the human senses, and recognize variations in quantities better than any natural sense can do, the superiority of electrical means is less marked when it comes to judging quality. For example, sound levels and frequencies can be measured without any difficulties, and so can light intensity and color. But where is the instrument which can tell us if a sunset scene is beautiful, a picture a masterpiece of art, or a tune masterfully played? A picture or a tune represent a combination of so many quantities that no apparatus has yet been built to present all these quantities and their interrelation as to time, space, frequency, and intensity. But, curiously enough, the human ear and the human eye are able to perform this intricate task quite efficiently.

In the fields of taste and smell our progress in measuring has been quite limited. Since we do not yet know with certainty the mechanism by which the human nose distinguishes a smell, we are handicapped in our efforts to measure. If, however, the assumption is correct that the basis of smell, other factors being equal, is simply chemical composition, we can go a long way in the direction of measuring it by using the analytical mass spectrometer. In this way it would be theoretically possible to chart the exact chemical composition of any gaseous substance and then to produce the same smell by reproducing the exact same chemical composition. Experiments that have been under way for some time along this line show much promise, but the evidence is not yet conclusive that we can really measure smell.

With respect to taste, too, our progress in measurement has been limited. Here, again, it seems likely that chemical composition is the basis of the sensation, and the same kind of analysis can be made with the mass spectrometer that we mentioned for smell. But the chemical combinations involved in taste are numberless, and the day is not yet here when we can make practical measurements of taste in terms of the findings of the mass spectrometer. Who would have the audacity, however, to deny that the day may come when we shall be able to do exactly that?

Measurement engineers are in no danger of becoming complacent like the scientists of the late nineteenth century who thought that all the important laws of science had been discovered. Those scientists did not foresee the epoch-making discoveries that were soon to come, and we cannot foresee the advances that will come in the art of measurement. But we can be sure they will come. Measurement is a dynamic art. While it has made great progress, there are still great opportunities for further progress, not only through refinement and perfection of methods already in use but also through extension into new and unexplored territory.

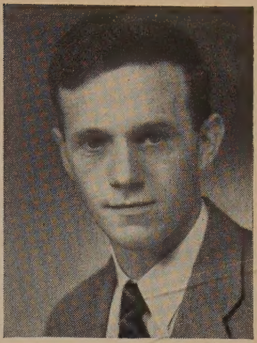
John A. Miller



ELECTRON AND ION BEAM INSTRUMENTS

Devices in which properties of the accelerated particle are utilized for purposes of measurement. Four electron instruments described are now finding wide use in industry

By DR. J. G. HUTTON
General Engineering and Consulting Laboratory
General Electric Company



John G. Hutton

THE realization of nuclear fission brought into brilliant focus high-voltage particle accelerators uch as betatrons and cyclotrons. Perhaps equally mportant, though less spectacular, were the cathode-ay oscillograph, the electron diffraction instrument, the lectron microscope, and the several manifestations of he mass spectrometer. While all the foregoing may be lassed as particle accelerators, it is only in the latter roup that the properties of the accelerated beam are tilized within the instrument for the purposes of neasurement. In view of this fact, and the rather omplete treatment already accorded high-voltage article accelerators throughout the scientific press, his article will consider only the measuring instrunents.

HE CHARGED PARTICLE

The physics of the atom, of molecules, and the tructure of matter began in 1853 with the discovery, rom experiments on electrical discharges through ases, of charged particles. Masson's observation of a right glow inside a sparked, partially evacuated glass essel, Geissler's gaseous discharge tubes, Hittorf's mproved vacuum techniques, and the work of Crookes aid the foundation. The various stages of discharge, as ressure decreases—the Faraday dark space, the rookes dark space—until the whole tube glows with faint greenish light, are well known. The green glow s due to fluorescence of the glass, produced by rays manating from the cathode and known as cathode ays.

In 1869 Hittorf discovered that cathode rays travel n straight lines; in 1870 Crookes demonstrated that hey have momentum and energy; in 1895 Perrin disovered that cathode rays are negatively charged articles. Further knowledge of the properties of these articles was gained by the work of Hertz and Lenard. t was realized that the individual cathode particles ere alike and were some common constituent of all orms of matter. Perhaps the most outstanding work hat led to the realization of this unit particle was that f J. J. Thomson, C. T. R. Wilson and H. A. Wilson, nd R. A. Millikan. To Johnstone Stoney, however, oes the credit of suggesting the name "electron."

During the late nineteenth century, while the properties of cathode rays were being investigated, Goldstein designed a special discharge tube and with it discovered canal rays. In 1896 Wien demonstrated, by means of a magnetic field, that these were positively charged particles. In 1911 Thomson showed, by measurement of their masses, that positive, or canal, rays resulted from ionization of gas molecules; that is, they are positively charged atoms or molecules of whatever gas is present in the ionizing apparatus; they are positive ions.

GENERAL REQUIREMENTS

Vacuum. Since electrons are particles with mass, they are very readily absorbed and scattered by matter. In order that the electron and ion beams used in these instruments may continue to exist and perform their respective functions, a highly evacuated tube or chamber is essential. The degree of vacuum for satisfactory performance differs with each instrument and will be treated more in detail in the sections covering the respective instruments.

The first vacuum experiments were performed about 1650 by Guericke, with his famous Magdeburg Hemispheres following four years later. By the time charged particles were discovered, some 200 years afterward, good vacuum techniques were available. Today the use of a rotary pump (for rough vacuum) together with a diffusion pump (for higher vacuum) is common practice; the latter may be of metal or glass, with either mercury or oil vapor as the pumping medium. Of late, however, the molecular pump has come into wider use. The type of vacuum system used depends upon the degree of vacuum necessary for the best operation of the instrument concerned.

Source of Charged Particles. The quantum theory of the structure of metals suggests that within a metal there is an ordered arrangement of atoms, each of which contributes one or more electrons to the so-called "electron gas" that circulates comparatively freely among the atoms. The remaining electrons are bound to the nucleus, about which they move in orbits, or shells, of different radii. It is the outermost, or valence, electrons which are released and allowed to circulate. Although these electrons are "free" in the sense of not being attached to a particular atom, they are under the

---

This article is so paged that, without mutilating other articles, it can be eadily removed for filing as a group of full-size consecutive pages.—EDITOR influence of the attractive field of the lattice as a whole, and hence are not free to escape. For this to occur, an electron must acquire additional energy to overcome the potential barrier. This may be done by any of the following means:

(*a*). Thermal excitation (thermionic emission)
(*b*). Lowering of the barrier (field or cold emission)
(*c*). Absorption of radiant energy (photo emission)
(*d*). Absorption of fast particles (secondary emission)

In general, the beam instruments to be described use electrons produced by thermionic emission. Because of this, only that phenomenon will be considered.

In order to raise the electron energy above the inner potential by thermal excitation, so that an appreciable number of electrons will be ejected from the surface, a temperature of some 2500 K is required. This is for a pure metal and may be reduced by oxidation of the metal surface or by contamination with another metal. Since very few metals remain solid at this temperature, it is usual to use tungsten or molybdenum plates or wires. A positively charged electrode, or anode, in the vicinity of the cathode prevents the accumulation of emitted electrons as a space charge round the cathode. Curves showing the variation in emission with temperature for different cathode materials are shown in Fig. 1.

Positive ions were first observed in a beam as they emerged through a canal, or aperture, in the cathode of a discharge tube. Thomson showed that they were the result of the ionization of gas molecules by collision with moving electrons. This mechanism is still the most commonly used method of producing a beam of positive ions.

CONTROL OF THE BEAM

During the course of experiments on the identification of charged particles, means for controlling them were also found. Essentially, they are the application of two simple relations that were evolved in the earlier work of Coulomb, Faraday, Henry, and Oersted. The relations are as follows:

(*1*) the force on a particle of charge e in an electric field of strength E is exerted in the direction of the field and is given by the equation

$$F = eE \qquad (1)$$

and (*2*) the force on a particle of charge e moving with a velocity v in a magnetic field of strength H is exerted at right angles to both the field and the direction of motion, and is given by the equation

$$F' = Hev \qquad (2)$$

Note that a perfect vacuum is assumed to exist, so that $H = B$, the magnetic induction.

The application of these equations to the particular instruments will be described in the appropriate sections.

BEAM DETECTION

The early experiments in particle physics utilized both fluorescent screens and photographic emulsions. This use has continued and advanced with the improved resolution of the detecting medium. In the cathode-ray oscilloscope, the electron diffraction instrument, and the electron microscope, full use is made of both techniques. In the mass-spectrometer type of instrument, however, use is made of the ion-beam current. This is possible because of developments in electronic components and circuits producing extremely sensitive electrometers and d-c amplifiers.

A series of instruments in which use has been made of the foregoing principles will now be described.

CATHODE-RAY OSCILLOGRAPH

When, in 1897, J. J. Thomson was doing his classical research on electrons and the determination of their mass, he actually had a cathode-ray tube in operation. Though used in a somewhat different manner from modern applications, the essential elements of this and a modern cathode-ray oscillograph are shown diagrammatically in Fig. 2. The combination of deflecting coils and plates is shown only for the purpose of illustrating different methods of deflection. In general, either deflecting plates or deflecting coils are used.

This type of electronic oscillograph tube was the first application of electron-optical principles to practical problems. In it a narrow electron beam of high intensity formed a small bright spot at the area of incidence of the beam on a fluorescent screen. When a difference of potential is applied to a pair of deflecting plates, or a current flows through deflecting coils, as

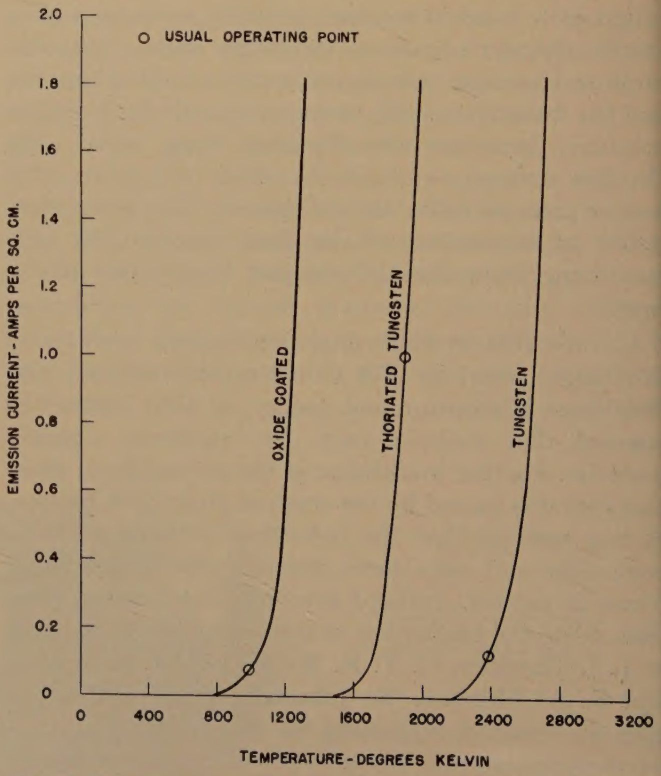


Fig. 1. Variation in the emission of electrons with temperature for different cathode materials

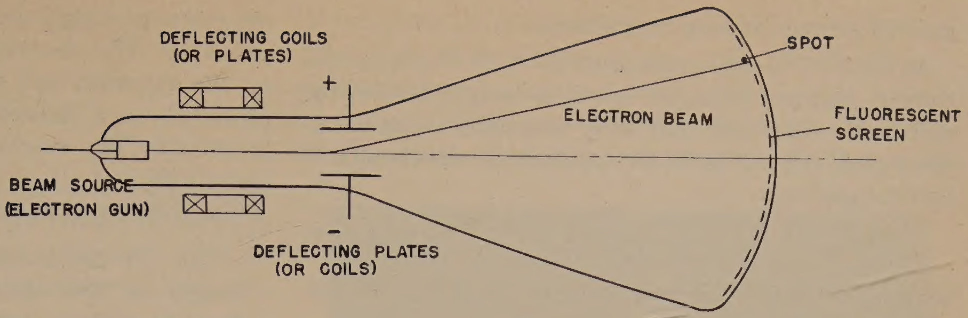


Fig. 2. Elements of a cathode-ray oscillograph. Both deflecting coils and deflecting plates are shown here only to illustrate different methods of deflection

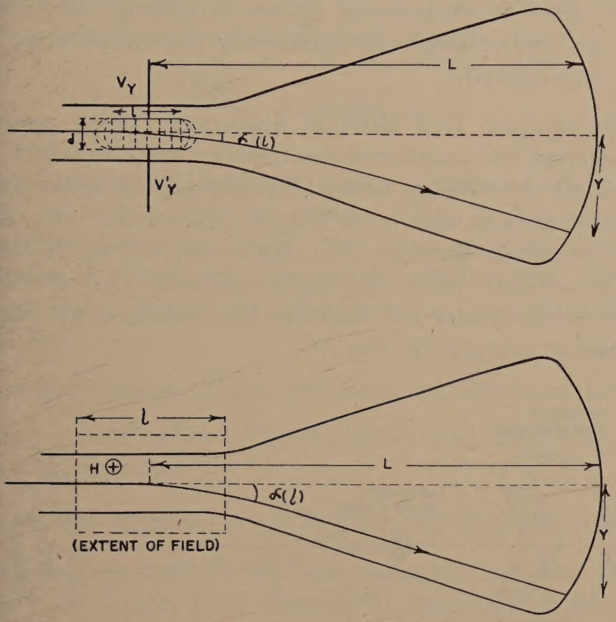


Fig. 3. Deflection of the electron beam in a cathode-ray tube. Electrostatic deflection is shown in the upper diagram, magnetic below

shown in Fig. 3, this bright spot is deflected. The amount of deflection is a measure of the applied voltage or the coil current, a purpose for which the oscillograph has found wide usage.

The deflection y, produced at the screen by the passage of the beam through a transverse electric field, is given by

$$y=\frac{lL}{2d}\,\frac{V_p}{V} \qquad (3)$$

where l is the length of the plates and d their separation. L is the distance from the transverse axis of the plates to the screen and is much greater than l. V is the accelerating voltage of the tube and $V_p(=V_y-V'_y$ in Fig. 3) is the voltage applied between the deflecting plates.

In a uniform transverse magnetic field the beam deviation x is perpendicular to the direction of the field and is represented by

$$x=K\frac{HlL}{V_p^{\frac{1}{2}}} \qquad (4)$$

Here l is the extent of the field H, and K a constant involving the mass-to-charge ratio of the electron. V_p is as in Equation (3).

Since 1897 considerable advance and refinement has been made, first along separate paths and then more recently along a combination of two. One such path marked the development of the hot-cathode sealed-off low-voltage tube with visual observation, or external photography, resulting in the familiar oscilloscope now so widely used. The second path was toward the continuously pumped cold-cathode high-voltage oscillograph with internal photography for the recording of very short-time phenomena.

The separate developments began to merge in 1937, when an instrument was described which used a hot-cathode sealed-off tube but operated at 15 kilovolts. By means of this tube it was possible to record a transient lasting only one microsecond, a feat comparable to those of the high-speed cold-cathode oscillograph.

The need for high-voltage surge measurements, and television and radar developments gave impetus to tube improvements. In Fig. 4 is shown an instrument with a 25-kv tube. Another unique feature of this instrument is the camera by means of which a one-microsecond transient can be photographed and the film developed, fixed, and projected within 30 seconds.

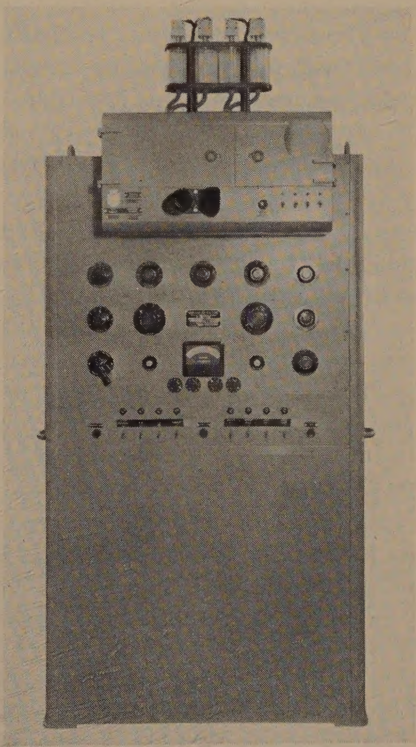


Fig. 4. Cathode-ray oscillograph, with a 25-kv tube, which photographs a microsecond transient and develops and projects the film within 30 seconds

ELECTRON DIFFRACTION INSTRUMENT

In 1924 de Broglie postulated the hypothesis that in certain respects material particles might behave as waves. He suggested that their momentum was quantized and related to their equivalent wavelength λ by the equation

$$mv = h/\lambda \qquad (5)$$

where v is the velocity and m the mass of the electron and h is Planck's constant.

If the motion of the electron is expressed in terms of its accelerating voltage V ($\frac{1}{2}mv^2 = Ve_s/300$) and relativity effects neglected, on inserting the appropriate numerical values

$$\lambda = \sqrt{150/V} \quad \text{Ångstrom units} \qquad (6)$$

For accurate work, when V is greater than 10 kv, the relativistic correction must be applied. Any wave motion will be diffracted in passing through apertures of the same order of size as the wavelength. An accelerated beam of electrons would, according to de Broglie's hypothesis, exhibit wave properties and therefore be diffracted as is light. From Equation (6) it will be seen that, for accelerating potentials greater than 150 volts, the wavelength is less than 1 Ångstrom unit (10^{-8} centimeter). Diffraction of electrons is therefore possible only through apertures of atomic dimensions.

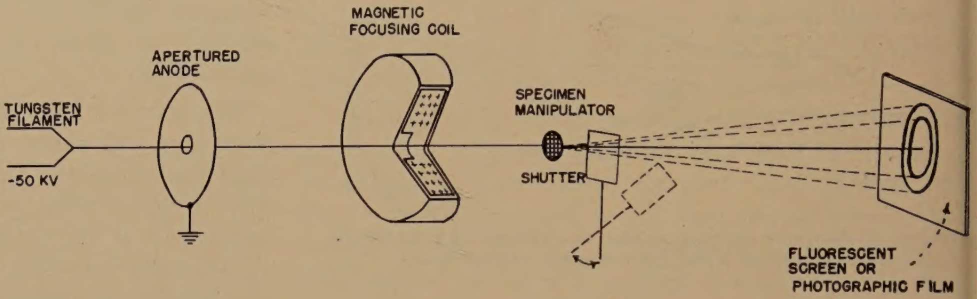


Fig. 5. Schematic diagram of components of an instrument for the study of electron diffraction

It is worthy of mention at this juncture that the first direct evidence of the wave nature of the electron was from concurrent demonstrations by Davisson and Germer, and G. P. Thomson, that electrons were diffracted by the regular array of atoms in a crystal lattice. It can be shown that the beam is diffracted so as to form a series of concentric circles whose positions and intensities are characteristic of the arrangement of the atoms within the crystal lattice.

A schematic diagram of a typical arrangement of components for electron diffraction studies is shown in Fig. 5, the components being housed in a continuously evacuated chamber. Scattering is negligible below a pressure of 10^{-4} millimeter of mercury, and an evacuation system sufficient for this would be provided by a two-stage air-cooled oil-diffusion pump and rotary back-up pump. In general no cold trap is necessary. A photographic reproduction of an instrument is shown in Fig. 6. To ensure a nearly homogeneous beam of electrons, a highly regulated accelerating potential is provided. The electron beam is magnetically focused on the specimen and the resulting diffraction pattern observed on a fluorescent screen or recorded photographically, an exposure of a few seconds generally being sufficient.

The diffraction pattern may be useful in two ways:

(1). If the crystal structure is known, the wavelength of the electrons may be calculated and Equations (5) and (6) confirmed.

(2). If electrons of known wavelength are used, the crystal structure of chemical substances may be investigated.

The electron is a particle with mass, being readily absorbed and scattered by matter and therefore of limited penetrating power. Specimen thicknesses may not be greater than a few hundred Ångstrom units, but transmission through thin films and reflection from solid objects yield intelligible patterns. An electron diffraction pattern of lead dioxide, obtained by transmission, is shown in Fig. 7.

The electron diffraction instrument has thus become an instrument of great importance for investigating the structure of matter and especially for the study of thin films and surfaces. It has been applied to the study of lubricants and bearing surfaces, contamination problems, the study of clay minerals and catalysts, problems associated with carbon brushes, and the study of secondary emission. Operation of the instrument is not difficult, but great care is required in the specimen preparation and interpretation of the results.

ELECTRON MICROSCOPE

The unaided human eye can normally distinguish points or lines separated by approximately two tenths of a millimeter. This is due to the limits of the lens structure of the eye and the coarseness of its retina. By the use of a microscope, object structure not normally discernible by the human eye can be enlarged to render visible the finer detail. A microscope with a magnification of ten would render visible details of structure separated by 0.02 mm.

In general, as the magnification is increased, more and more fine structure is revealed, but beyond a certain limit further enlargement of the image results only in outlines becoming diffuse in proportion to the enlargement. It can be shown that the maximum useful magnification M_u of any image formed by an objective is

$$M_u = \frac{0.033\, n \sin \alpha}{\lambda} \qquad (7)$$

where λ is the wavelength of the radiation by means of which the image is formed, n is the refractive index in which the object is immersed, and α the half angle, or aperture, of the rays; $n \sin \alpha$ is the numerical aperture.

If the resolving power or limit of resolution d is designated as the minimum distance separating two points which can be distinguished as such, then

$$d = \frac{0.61\,\lambda}{n \sin \alpha} \text{ Ångstrom units} \qquad (8)$$

In commercial light-microscope objectives using a medium with a refractive index of 1.5, the numerical aperture is approximately 1.4. The shortest wavelengths of visible light are of the order of 4000 Ångstrom units. Hence, by substituting in Equations (7) and (8)

$M_u = 1150$ (approx.) $d = 1700$ (approx.) Ångstrom units

Using quartz optics and ultraviolet light, these values may be improved to

$M_u = 1800$ (approx.) $d = 1100$ (approx.) Ångstrom units

In order to improve the limit of resolution so that the study of details finer than 1000 Ångstrom units is possible, radiations of shorter wavelength must be used.

In the preceding section on electron diffraction it was shown that high-speed electrons had associated with them a wavelength, and that they behaved in some respects as light. This wavelength λ was expressed by

$$\lambda = \sqrt{150/V} \text{ Ångstrom units} \qquad (6)$$

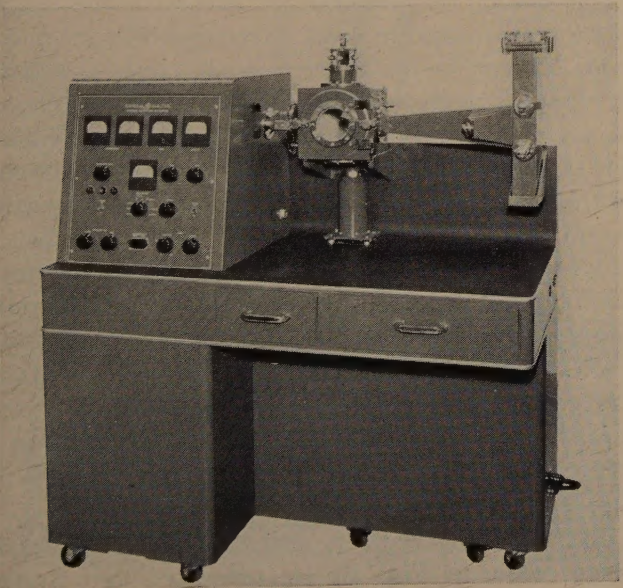


Fig. 6. Electron diffraction instrument

V being the potential difference in volts through which the electrons have been accelerated. Just as glass or quartz may be used as lenses in light optics, electric or magnetic fields may behave as electron lenses. Thus the essential elements of an electron microscope are available. In spite of the extremely short wavelength possible with electrons, aberrations in electron-optical systems set the practical limit of resolution to the order of 10 Ångstrom units, a gain of some 100 over that of the ultraviolet microscope.

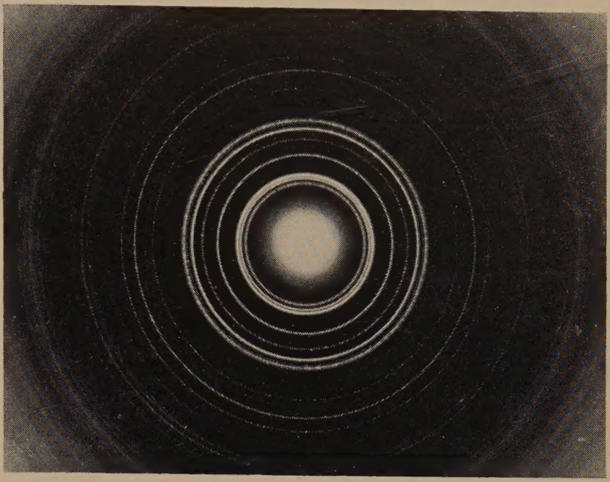


Fig. 7. Photographic diffraction pattern produced by the electron diffraction instrument

Both magnetic fields and electric fields have been used in electron microscopes for the formation of electron images. In Fig. 8 is shown a schematic comparison of the light microscope and electron microscopes, one using magnetic lenses, the other using electrostatic lenses.

In the light microscope the source is generally a suitable incandescent lamp. The filament of this lamp is imaged by a condenser lens into the lower focal plane of the objective. The object is usually mounted on a glass slide, and by refraction, scattering, absorption, and diffraction, light rays leave the various parts of the object, differing in color intensity and divergence from the original rays. These modified rays are unique for the particular area of the object explored and completely analyze its transmission properties. By refraction through the objective an intermediate image is formed. The central portion of this image is again refracted by the projector lens, or eyepiece, forming the final image on either a photographic plate or a ground-glass screen.

The incandescent lamp of the light microscope is replaced by an electron source in the electron microscope. This source may be either a cold cathode or a hot filament, the latter being in more common use. The electrons leaving the source are accelerated by the potential difference between the filament and an apertured anode, reaching a velocity which is essentially constant throughout the instrument.

In the magnetic electron microscope the convergence of the electrons on the object is regulated by a magnetic condenser lens consisting of a coil enclosed in a soft-iron shield with a central ring air gap. Variation of the current in the coil changes the condensing effect of the lens.

As was pointed out earlier, electrons are readily scattered and absorbed by matter. Objects prepared for use in electron microscopy are therefore similar to those used for transmission work in the electron diffraction instrument. The specimens in general are a few hundred Ångstrom units thick, mounted on membranes of approximately the same thickness and supported by fine-mesh copper screens.

The electrons, in passing through the object, are diffracted and scattered, the degree of scattering depending on the density and thickness of the material of the object. The analogy with the light microscope is now very close. The intensity of the central section of the electron beam leaving the object is again unique for the object being studied and completely analyzes its transmission properties. The central electrons are refracted by a magnetic objective lens of somewhat different pole-piece structure from the condenser lens.

Further refraction of the central portion of the magnified image by a magnetic projector lens results in a greatly magnified final image, which may be viewed on a fluorescent screen or preserved by means of a photographic plate, generally only a few seconds' exposure being necessary. The focus of the image is varied by change of current in the coil of the objective lens, while adjustment of current in the projector lens controls the magnification of the final image. High regulation of the coil currents and accelerating voltag is necessary, but the ultimate performance of th instrument is high.

In the electrostatic electron microscope the lense are unipotential and consist of two grounded oute disks with small apertures and a larger-aperture central disk connected to the filament. The convergenc of the electrons on the object may be controlled b either a condenser lens or a grounded anode aperture The modified beam is refracted by an electrostati objective, and the central portion of the intermediat image is further refracted by the projector. As in th magnetic electron microscope, the final image may b viewed on a fluorescent screen or photographed.

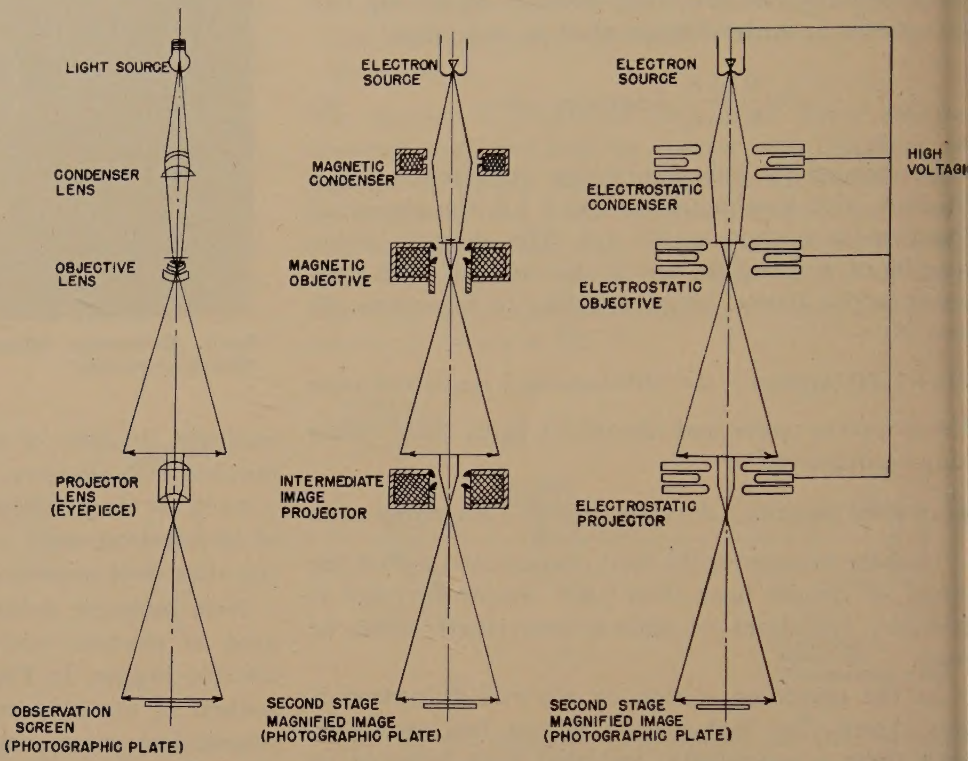

LIGHT SOURCE
CONDENSER LENS
OBJECTIVE LENS
PROJECTOR LENS (EYEPIECE)
OBSERVATION SCREEN (PHOTOGRAPHIC PLATE)
ELECTRON SOURCE
MAGNETIC CONDENSER
MAGNETIC OBJECTIVE
INTERMEDIATE IMAGE PROJECTOR
SECOND STAGE MAGNIFIED IMAGE (PHOTOGRAPHIC PLATE)
ELECTRON SOURCE
ELECTROSTATIC CONDENSER
ELECTROSTATIC OBJECTIVE
ELECTROSTATIC PROJECTOR
SECOND STAGE MAGNIFIED IMAGE (PHOTOGRAPHIC PLATE)
HIGH VOLTAG

Fig. 8. Schematic comparison of the light microscope (*left*) and electron microscopes, one using magnetic (*center*) and the other electrostatic lenses

The use of the unipotential lens with the centra electrode connected to the filament simplifies the microscope. Except for the filament supply, only one sourc of voltage is necessary. Small variations in this voltag do not materially affect the sharpness and magnification of the image because the lens action depends onl on the ratios of the electrode potentials. Theoretically aberrations in electrostatic lenses are greater than i magnetic lenses. However, many other practical considerations enter into ultimate performance evaluations and at the present time the two are quite comparable

The evacuation system may either be similar to tha used in the electron diffraction instrument or ma consist of a water-cooled mercury-diffusion pump wit cold trap, with a rotary rough pump for initial evacuation and back-up.

In FIG. 9 is shown a typical electromagnetic microscope, while in FIG. 10 are presented two electro micrographs.

Electrically charged particles, under the influence of a common accelerating voltage, have identical trajectories in electrostatic fields regardless of their mass-to-charge ratio. In electromagnetic fields, however, their paths deviate and the particles may be separated according to their mass-to-charge ratio. In order to take advantage of this phenomenon in a practical way, a combination of electric and magnetic fields is necessary, the electric field being essential for the production and collimation of an ion beam.

In the electric field, the kinetic energy gained by the ion in falling through a potential E is given by Equation (1); that is

$$eE = \tfrac{1}{2}mv^2 \tag{7}$$

where m is the mass and v the velocity of the particle.

In the magnetic field, the particles assume a radius of curvature r. The centrifugal force exerted on them will be balanced by the force due to the magnetic field; and, from Equation (2),

$$\frac{mv^2}{r} = Hev \tag{8}$$

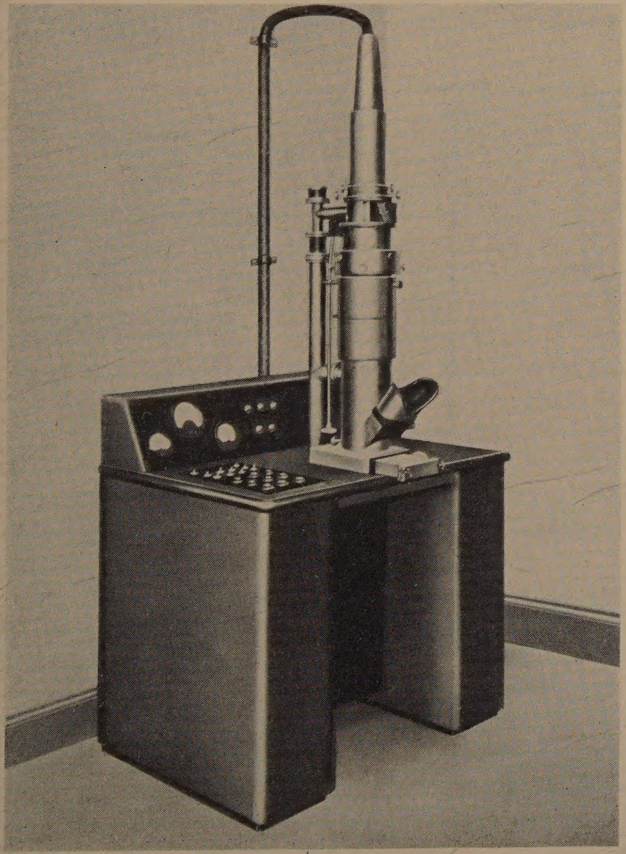
Solving for v and substituting in Equation (7)

$$\frac{m}{e} = \tfrac{1}{2}\frac{H^2r^2}{E}$$

which in practical units, E volts and H gausses, is

$$\frac{m}{e} = \frac{H^2r^2}{E} \times 4.82 \times 10^{-5} \tag{9}$$

This, essentially, is the fundamental equation of the mass spectrometer.



(Courtesy Metropolitan-Vickers Electrical Co. Ltd.)

Fig. 9. Artist's conception of an electron microscope

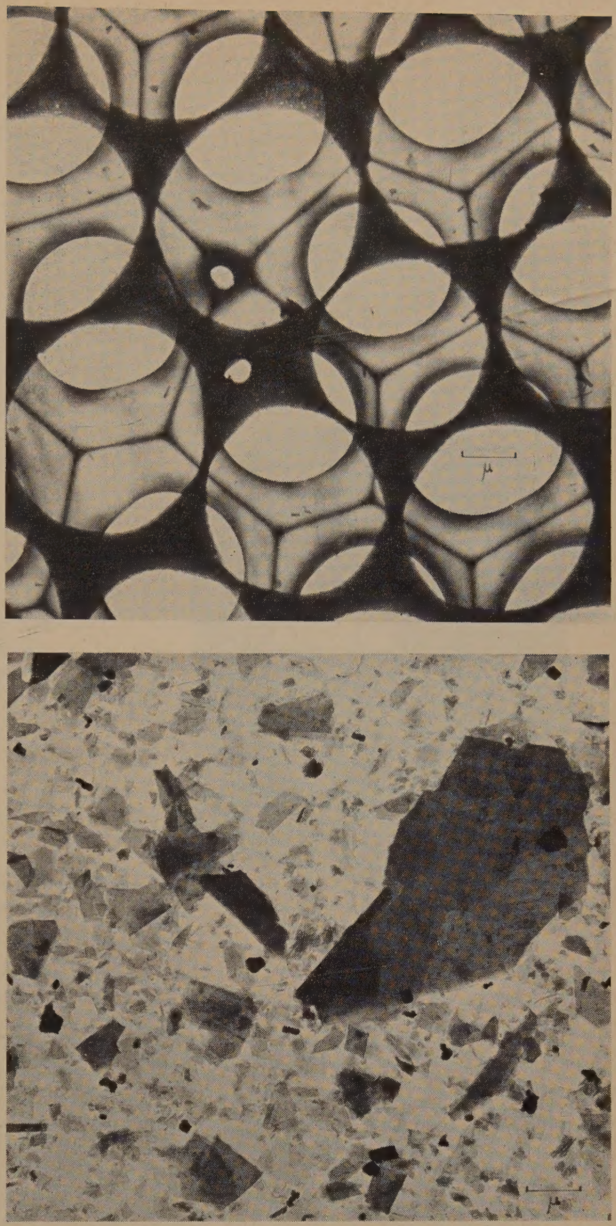


Fig. 10. Electron micrographs of a diatom (*top*) and a sample of face powder (*bottom*)

The first mass spectrometer was that of J. J. Thomson, which he used in his work on positive-ray analysis. The apparatus had a system of concurrent electric and magnetic fields and used a cold-cathode discharge for the production of positive ions. The method had a resolution corresponding to a mass difference of approximately five percent, a limitation set largely by the wide ion-velocity distribution.

F. W. Aston was able to improve resolution greatly by using electric and magnetic fields which crossed at right angles. In this way all ions of common mass-to-charge ratio are brought to a common focus, whatever their velocity. Both abundance sensitivity and resolution were increased, it being possible to compare the ratio of two masses to one part in 10,000 and to distinguish ions differing in mass by one part in 600. In a uniform transverse magnetic field, ions of differing mass will be brought to a different focus on the plane

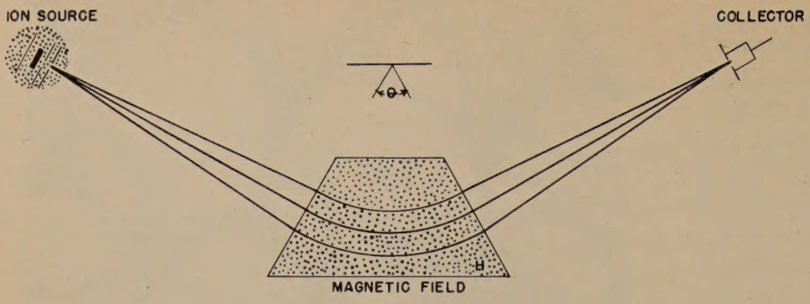


Fig. 11. Sector-type magnetic field of the mass spectrometer

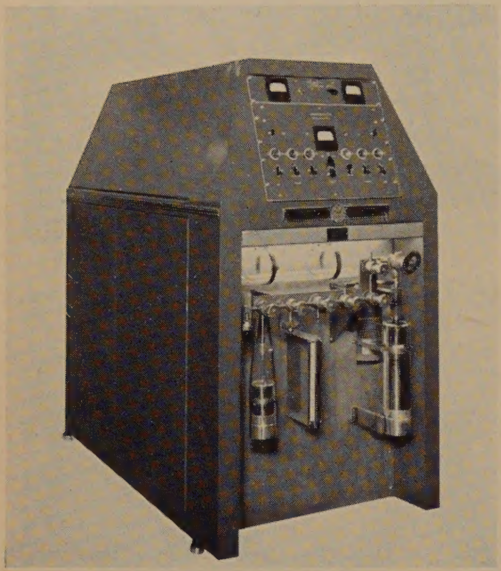
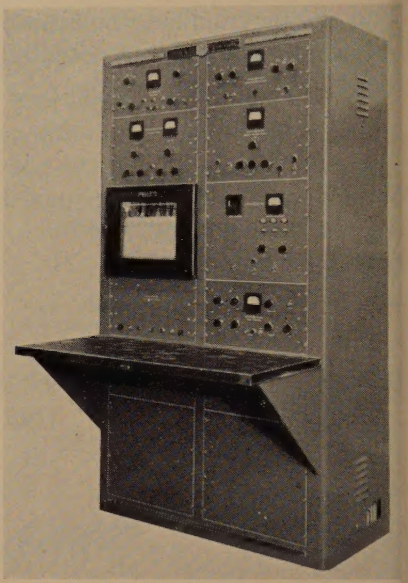


Fig. 12. Tube rack (*left*) and relay rack (*right*) for the analytical mass spectrometer



of the source. By using electrons from a thermionic filament to ionize the gas or vapor under investigation, and accelerating the ions to an essentially nomochromatic beam, A. J. Dempster was able to obtain sharp focus. He was able to distinguish between ions differing in mass by one part in 4000.

In 1933 N. F. Barber showed that if the central section of a diverging beam of ions enters and leaves a uniform magnetic field perpendicular to the pole edges, the ions are brought to a focus on the line extending from the source through the center of curvature of the central beam, as shown in Fig. 11. The first use of such a property in a sector-shaped field in mass spectrometry was reported in 1940 by A. O. C. Nier. An instrument similar to his design is shown in Fig. 12, while Fig. 13 is a schematic diagram representing the operation of the instrument.

Neutral molecules of the gas or vapor to be analyzed enter the spectrometer tube by pressure flow through a suitable leak. An electron beam of suitable energy, focused magnetically, traverses the gas or vapor and, by impact, releases one or more electrons from some molecules of each of the constituents of the mixture. The positive ions are then collimated and accelerated to an essentially uniform velocity by the lens system shown. The mixed ions emerge from the lens as a thin ribbon and are separated according to their mass-to-charge ratio in the magnetic field by virtue of Equation (9).

At the other extremity of the tube is a suitable slit arrangement through which will fall, for a given voltage, magnetic field, and tube configuration, one particular group of ions satisfying Equation (9). The ions are collected and the current amplified by means of a

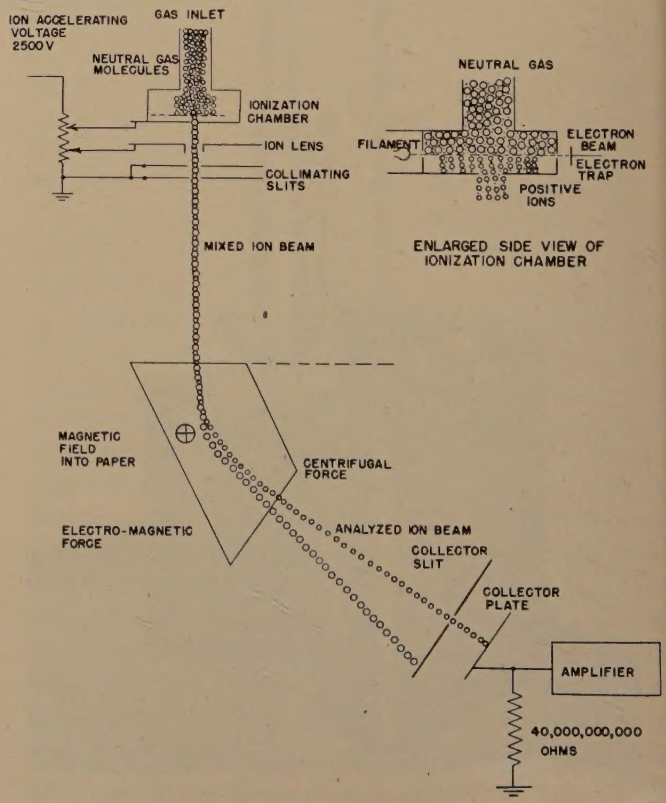
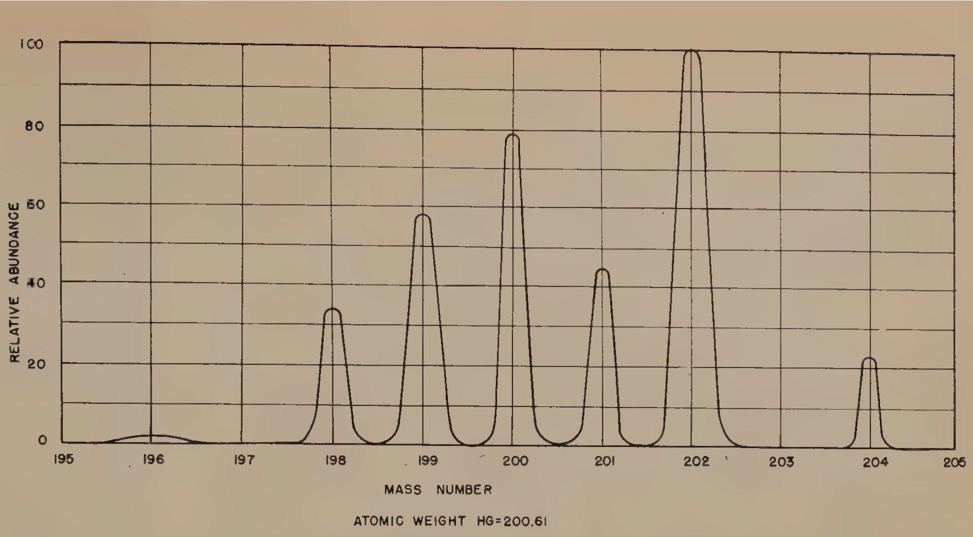


Fig. 13. Schematic diagram of the operation of the mass spectrometer



ig. 14. Typical spectra of mercury sotopes recorded by the mass spec-rometer

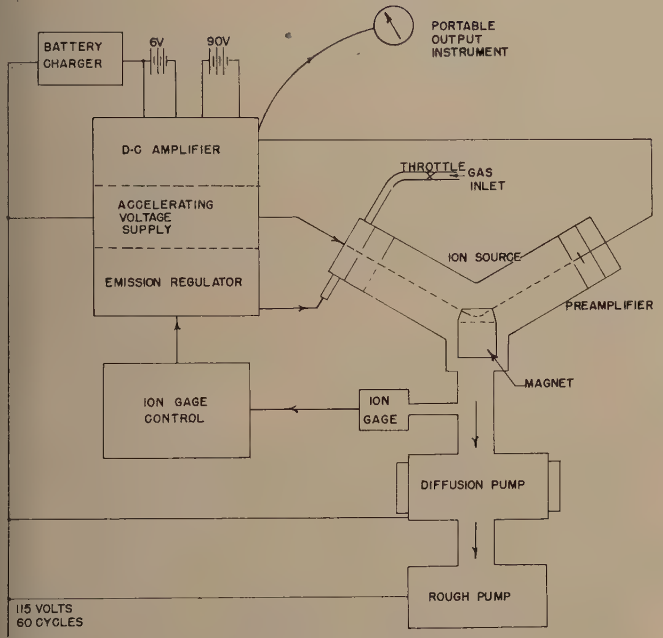


Fig. 15. Block diagram of the leak detector

high-impedance d-c amplifier, to be either measured by a galvanometer or recorded.

By suitably varying either the voltage or the magnetic field, a range of ions of different masses can be collected in turn; thus a "mass spectrum" of the gas or vapor is obtained. Because of the variation of the mass-to-charge ratio with the square of the field, by varying the latter a wide range of masses can be collected conveniently. This is done automatically in the instrument depicted in Fig. 12, and the ion currents recorded on a pen-and-ink recorder. Typical spectra are shown in Fig. 14.

Other features of the instrument are automatic sensitivity-range changing, automatic mass marking and registering, and ease of servicing. The sensitivity of the instrument is exacting with respect to cleanliness and vacuum conditions. To this end a minimum of joints are used and these are waxed. For evacuation purposes a water-cooled mercury-diffusion pump, with suitable refrigeration, and a rotary pump are used, producing a tube pressure of less than 10^{-6} millimeter of mercury. A mass range from 1 to 350 can be covered at one voltage setting and any mass can be rescanned at will. The instrument is of great value in chemical analysis, hydrocarbon analysis, isotope work, and in following the kinetics of chemical reactions.

If, instead of variation of the magnetic field, the accelerating potential is varied in steps, the mass spectrometer can be readily adapted to process control. In a hydrocarbon mixture it may be necessary to monitor several constituents. By means of a suitable relay system, a repeating cycle of operations may be run. In this system, voltages would be set in turn to correspond, by Equation (9), to one mass of each of the constituents to be monitored. If ion currents were recorded, an operator would be able to control operations by watching for excessive variations on the record. Alternatively, one of the current variations could be used as a means of automatic control of the process or to actuate a warning system.

If, in Equation (9), the magnetic field and accelerating voltage are fixed, only one mass would pass through

(Concluded on following page)

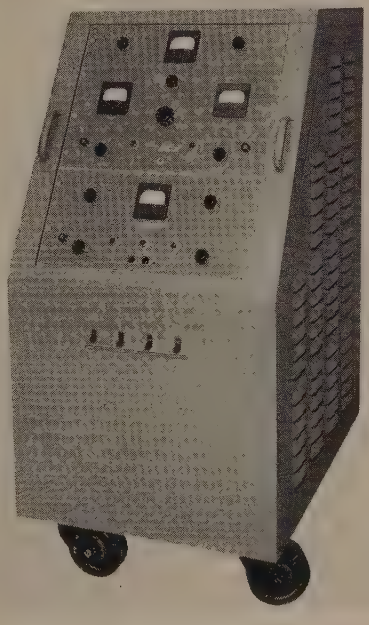


Fig. 16. Leak detector and associated ion gage

ELECTRITE

A high grade fibre board for electrical insulation. A material of quality possessing high tensile and dielectric strength. Used by many of the leading manufacturers of electrical equipment.

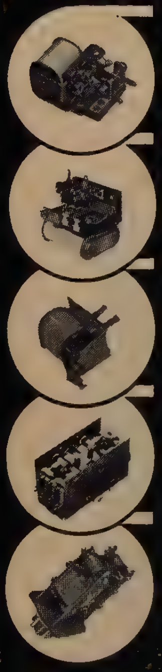
DENSITE

An extremely hard board of superior quality which can replace the more expensive types of insulating materials.

Pulp Products Department

WEST VIRGINIA PULP & PAPER COMPANY

230 Park Avenue, New York, N.Y. 35 E. Wacker Drive, Chicago, Ill.



SIGMA SENSITIVE RELAYS

SERIES 4

SPDT GENERAL PURPOSE. Modest cost. Suitable for aircraft applications, and vacuum-tube-operated relay circuits. Precision adjustments for pull on, drop out. Nominal contact rating 2 amp. Coil resistance up to 14,000 ohms.

SERIES 5

SPDT VERY SENSITIVE. Exacting performance as low as 5 milliwatts input. Undamaged by 500g shock. Nom. contact rating 2 amp. Coil resistance to 16,000 ohms.

Special Adaptations: — Built-in rectifier, two coil differential operation, constant voltage temperature compensation.

SERIES 41

SPDT AC — DC — KEYING. DC sensitivity compares with Series 4, AC sensitivity better than 0.1 V.A. Long life for high speed keying and counting. Mechanical life over 10^9 operations. Contact ratings to 5 amp. or over. Coil resistance to 14,000 ohms.

SERIES 6

MULTICIRCUIT POLARIZED. Single or double windings (differential). Resistance to 25,000 ohms. Contacts up to 4PDT, 5 amp. nominal rating.

Form X (Three Position or Null-Seeking) for automatic positioning, 2-way process control, etc. Form Y (biased — spring return). Used as conventional sensitive Relay, requiring complex contacts. Responds to D. C. of only one polarity. Form Z (latching — permanent, magnetic). Longer life, greater resistance to vibration than mechanical latch electrical reset relays.

SERIES 7

HIGH SPEED POLARIZED. Single or multiple windings up to 14,000 ohms (single). Fully balanced armature. 2 amp. nominal rating. Especially designed for repeating telegraphic signals at speeds up to 250 words per minute. Exceptionally free from distortion and chatter. Long life. Forms X, Y, Z available. (See Type 6 above).

SIGMA **Sigma Instruments, INC.**

Sensitive RELAYS

93 CEYLON ST., BOSTON 21, MASS.

Most Sigma relays are available in a variety of enclosures including hermetically sealed cases. Write for fully descriptive catalog.

ELECTRON AND ION BEAM INSTRUMENTS

(Continued from preceding page

the slit and be collected. Such an arrangement i eminently suitable for leak detection. A block diagram of a leak detector is shown in Fig. 15, and Fig. 16 is general view of an instrument. Helium gas of mass 4 i highly useful for the purpose; it is present only in negligible quantities in the atmosphere; is inert, odorless and nontoxic; and is relatively inexpensive.

The vessel to be leak-tested is first exhausted through a manifold until a suitable degree of vacuum is obtained. By means of suitable valves, the vessel i then connected to a leak detector without breaking vacuum and the outside of the vessel is "probed" with a fine jet of helium gas. A leak would allow the helium to enter the spectrometer and a registration of ion current would be obtained. In this way the leak position would be determined. Leaks which allow the flow of one standard cc of air in half a million years may be located in this way. The ultimate instrument sensitivity is such as to detect one part of helium in 200,000 parts of air at the pressure of the tube. Either water-cooled mercury-diffusion pumps or air-cooled oil-diffusion pumps can be used for evacuation purposes.

Many applications are being found for this instrument, typical examples being the vacuum-tube and domestic-refrigerator industries and atomic energy plants.

9,000 hp Synchronous Motor, manufactured at C-G-E Peterborough Works, driving a centrifugal compressor at a large Canadian nickel mine.

In Canada . . .

ten factories manufacture General Electric products. 30 engineering and sales offices and 19 warehouses are located from coast-to-coast to serve you.

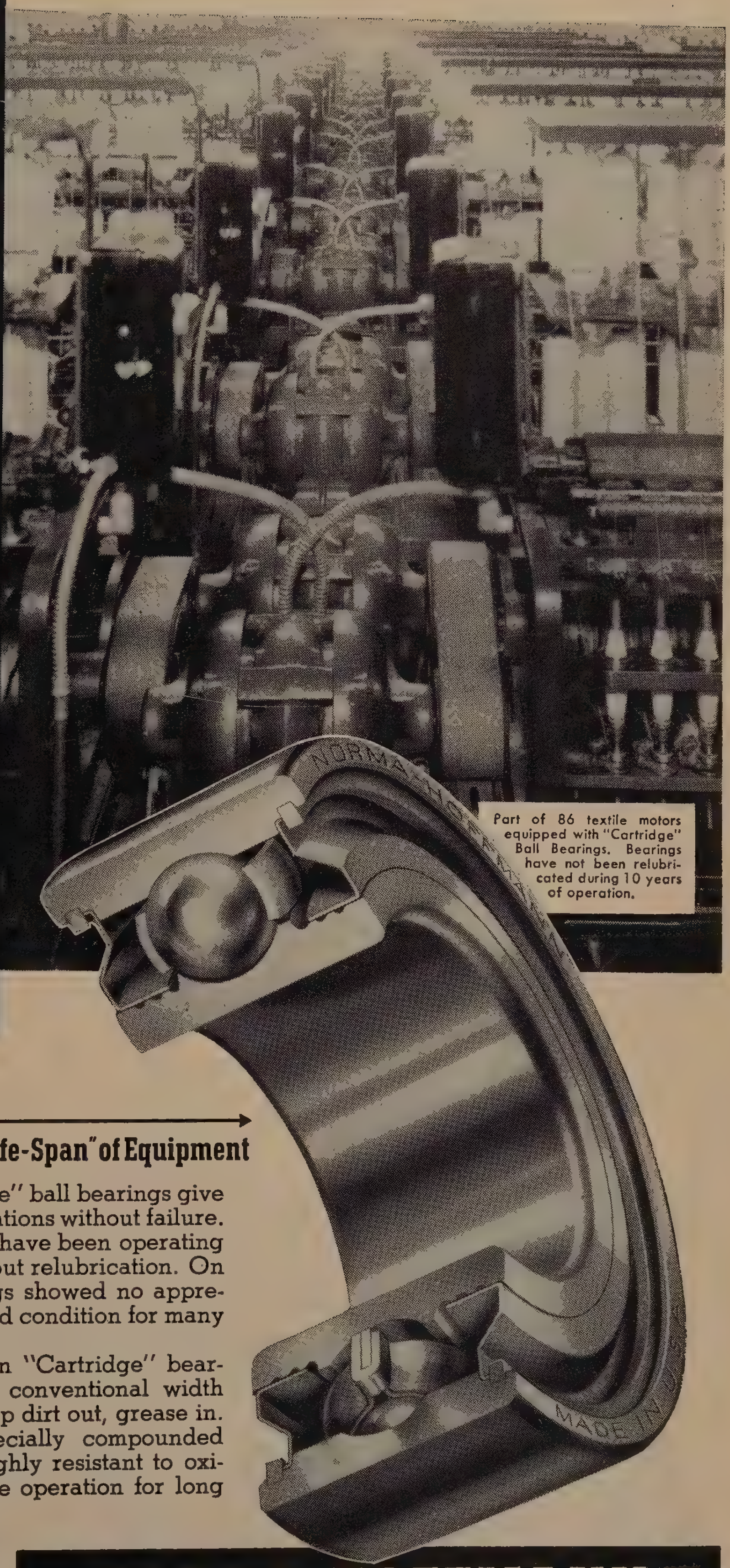
CANADIAN GENERAL ELECTRIC CO

LIMITED

Sydney • Halifax • Saint John • Quebec • Chicoutimi • Trois Rivieres • Sherbrooke • Montreal • Ottawa • Toront
Hamilton • St. Catharines • London • Windsor • Noranda • New Liskeard • Sudbury • Timmins • Fort William
Winnipeg • Brandon • Regina • Saskatoon • Lethbridge • Edmonton • Calgary • Trail • Kelowna • Vancouver • Victori

CASE HISTORY #819

646 Motors Operate 8 to 10 Years Without Relubrication or Bearing Failures ...and they're still going strong


Part of 86 textile motors equipped with "Cartridge" Ball Bearings. Bearings have not been relubricated during 10 years of operation.

Norma-Hoffmann

atented "Cartridge" Bearings increase the "Life-Span" of Equipment

ecords prove that Norma-Hoffmann "Cartridge" ball bearings give ontinuous performance in hundreds of applications without failure.

For example — 646 motors in 5 textile mills have been operating ractically continuously for 8 to 10 years without relubrication. On nspection of many of the motors, the bearings showed no appreiable wear and the original grease was in good condition for many nore years of operation.

Made to double-row width, Norma-Hoffmann "Cartridge" bearngs have 100% more grease capacity than conventional width ealed bearings. The highly efficient seals keep dirt out, grease in. actory-packed with Norma-Hoffmann's specially compounded stability-tested" grease . . . grease that is highly resistant to oxiation and breakdown . . . assures dependable operation for long eriods without regreasing.

Investigate the "Cartridge" ball bearing r your products whether they be motors, mahine tools, pumps or other machinery. Our ngineers are always available for consultion about your bearing applications. Write r their services.

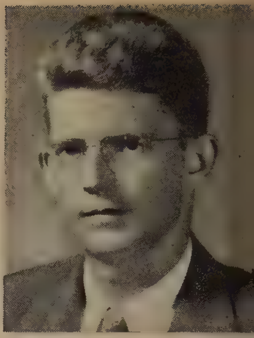
NORMA-HOFFMANN
Precision **BEARINGS**
BALL • ROLLER • THRUST

NORMA-HOFFMANN BEARINGS CORPORATION, STAMFORD, CONNECTICUT

d Offices: Chicago • Cleveland • Detroit • Cincinnati • Los Angeles • San Francisco • Dallas • Seattle • Phoenix

PRECISION SPEED MEASUREMENT OF ROTATING EQUIPMENT

Instantaneous speed as a factor in the determination of motor efficiencies must sometimes be measured to an accuracy of twenty-five thousands of one percent. A method is described



Martin W. Hellar, J

By MARTIN W. HELLAR, JR.
Fort Wayne Works Laboratory
General Electric Company

AS AN aid in the design and manufacture of motors it is frequently desirable that speed be measured with high precision. For example, it is sometimes necessary to determine the efficiency of a four-pole induction motor with an accuracy of at least plus or minus one percent. To do this, very accurate measurements of speed, torque, and watts input are necessary. Usually it is considered good practice to maintain equal accuracies in all measured quantities. Therefore, an accuracy of ±0.2 of one percent is necessary in measuring these three quantities to limit the maximum error in the determination of efficiency to plus or minus one percent.

Statistically, it can be shown that for these conditions in the vast majority of cases the accuracy in the determination of efficiency will be considerably better than plus or minus one percent. It can be shown also that increasing the accuracy of the measurement of speed to ±0.025 percent will practically eliminate this quantity as an influence upon the over-all accuracy in the determination of efficiency. The error in efficiency will be reduced to ±0.425 percent if the accuracy of the speed measurement is ±0.025 percent and if torque and watts are each maintained at 0.2 percent accuracy.

Complete elimination of the error in measuring spee would only increase the accuracy of efficiency fro ±0.425 to ±0.400 percent. Therefore, a further improvement in the accuracy of the measurement o speed can not be warranted with the stipulated accuracy of torque and power input. Although equipmen is available commercially which will measure averag speed with any desired precision, the best accuracy t be expected for measuring instantaneous speed is abou ±0.5 of one percent. Measurement of instantaneou speed is desired in the determination of efficiency sinc

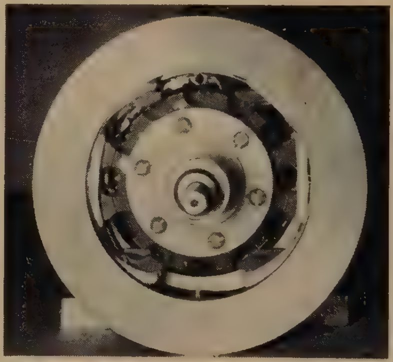


Fig. 2. End view of one of the alternators used as frequency standard. Note the two sets of notches in the rotor structure

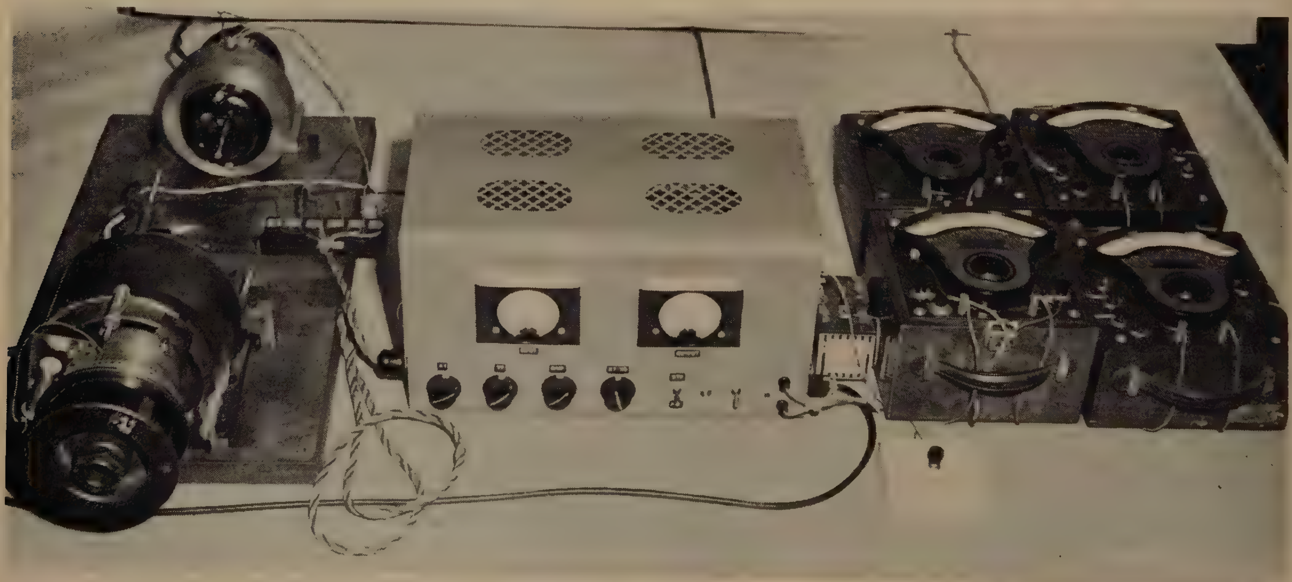


Fig. 1. Instrument for precise measurement of instantaneous speed. The frequency standard is a synchronous motor driving a special induction alternator

---

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

present measuring techniques as applied to torque and watts utilize instantaneous measurements.

OPERATING PRINCIPLES

An instrument (Fig. 1) is to be described which will measure instantaneous values of speed with an accuracy of ±0.025 per cent over a range of 1710–1780 rpm and an accuracy of ±0.125 percent over a range of 1350–1700 rpm. The latter permits the determination of speed at breakdown torque.

Since speed is to be measured over a partial range, a dynamometer-type frequency meter is uniquely suited as an indicating device in that it is an inherently accurate instrument and the principle of the expanded scale may be utilized. In this way the error of the meter is limited only to the range of speed to be measured and thus the over-all accuracy of the measurement is increased. For instance, consider two indicating instruments, each having an accuracy rating of 1 percent of the scale range. The first—a conventional 0–1800-rpm instrument—has an absolute accuracy of 18 rpm. The second instrument has a measurement range of 1710–1780 rpm, a scale interval of 70 rpm, 1 percent of which is 0.7 rpm. The accuracy is, therefore, increased over 25-fold by limiting the measurement range of the instrument to the desired range in speed. While this statement rigorously applies to observational errors only, other sources of instrument error tend to follow the same rule.

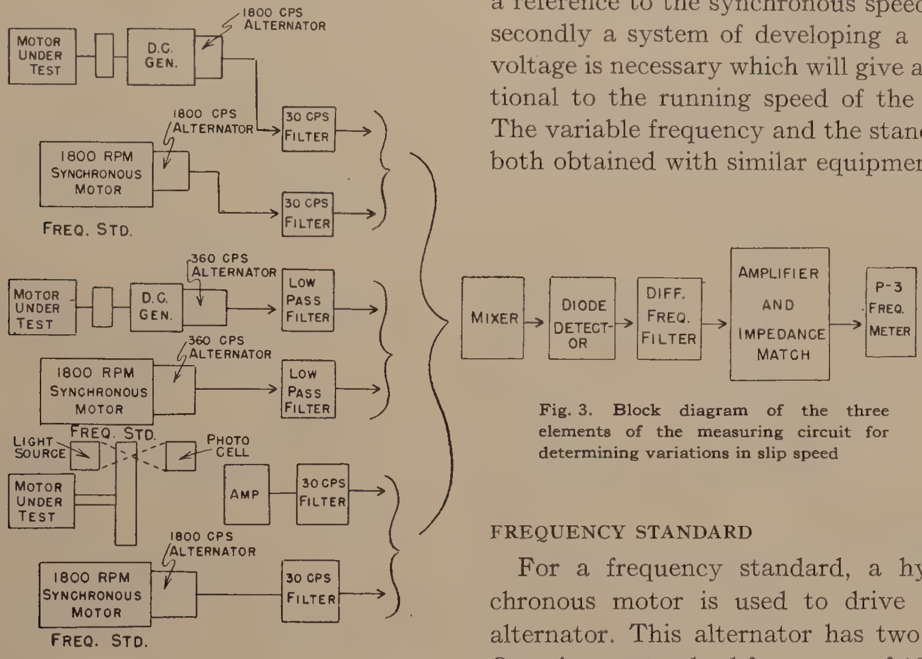


Fig. 3. Block diagram of the three elements of the measuring circuit for determining variations in slip speed

A second important point in the development of this instrument is that the synchronous speed of all motors to be tested was 1800 rpm. Therefore, a fairly accurate measurement of slip speed would result in a very accurate measurement of running speed. Consequently, a constant-frequency standard is necessary which acts as a reference for the motor speed as related to the synchronous speed. In other words, if some frequency can be made to vary with the motor speed and a constant frequency is used as a reference for the synchronous speed, the difference between these two frequencies would be a measure of slip speed.

The range of slip speed to be measured is 20–90 rpm. Frequency meters of the electrodynamometer type are commercially available with a range of 20–90 cps and an accuracy of ±0.3 cps. Consequently, if the frequency standard is made equal in cps to the synchronous speed in rpm, and similarly if the frequency generated by the motor under test is equal in cps to the motor running speed in rpm, the difference frequency in cps is then equal to the slip speed in rpm. Utilizing the 20–90-cps meter, slip speed can be measured with an accuracy of ±0.3 rpm. This also permits a measurement of running speed to an accuracy of 0.3 rpm if an absolute frequency standard is used. Therefore, first an accurate frequency standard is necessary which will be a reference to the synchronous speed of 1800 rpm, and secondly a system of developing a variable-frequency voltage is necessary which will give a frequency proportional to the running speed of the motor under test. The variable frequency and the standard frequency are both obtained with similar equipment.

FREQUENCY STANDARD

For a frequency standard, a hysteresis-type synchronous motor is used to drive a small induction alternator. This alternator has two separate outputs. One gives a standard frequency of 1800 cps; the second output gives a standard frequency of 360 cps. The principle of operation of this alternator is the interruption of a d-c field by a notched gear. For each section of the alternator two field windings are utilized. One winding produces a d-c field. This field is varied by the action of the rotor. These variations in field strength cause an a-c voltage to be induced in the second winding. Since a two-pole field is used and the synchronous motor is rotating 1800 rpm, a sixty-tooth rotor will produce the necessary standard frequency of 1800 cps.

A second set of windings and a twelve-tooth rotor will produce a 360-cps standard frequency. This lower standard frequency is used to measure motor speed at breakdown torque. An end view of one of the alternators is shown in Fig. 2.

GENERAL DESCRIPTION

A block diagram of the equipment used for speed measurement is shown in Fig. 3. This block diagram

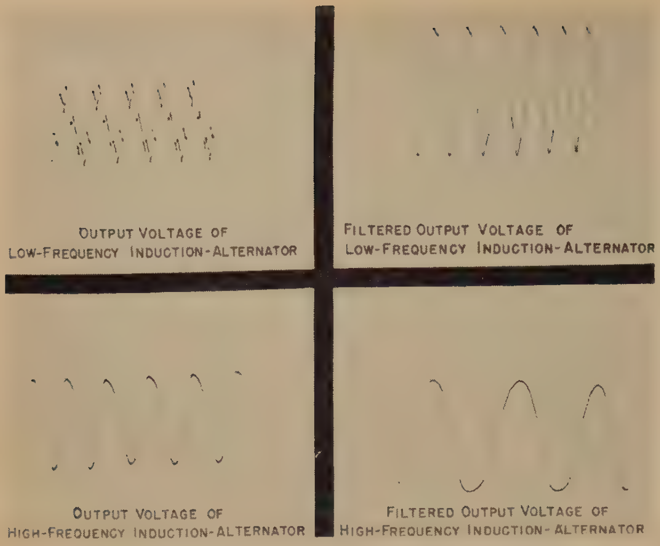


Fig. 4. Four voltage traces showing effects of various filters

shows that there are three separate input systems, all feeding into the same electronic circuit and all utilizing the same frequency meter. Since all three input systems are based upon the same principle, the first system will be described in detail and the modifications of the other two input systems pointed out later.

The motor to be tested is coupled to a loading device such as a direct-current generator or a prony brake. For the purpose of this description, a direct-current generator used as a dynamometer will be considered as a loading device. The particular generator used also contains one of the induction alternators which is identical to the one incorporated in the frequency standard. The output of the sixty-tooth section of this alternator will give a voltage whose frequency (in cps) is equal to motor running speed (in rpm). This variable-frequency voltage (which we shall call the signal frequency) is then fed into the instrument. Likewise the 1800-cps standard frequency is fed into the instrument. These frequencies are both passed through high-pass filters to eliminate a 30-cps component which is due to a once-around reluctance variation. The output voltages from the filters are then mixed by feeding the two voltages in series to the next stage of the unit. At this point a nonlinear device is utilized which will permit the separation of the difference frequency from the two fundamental frequencies. This voltage, with a frequency equal to the difference of the two frequencies, is filtered out and then amplified. The output of the amplifiers is coupled to the frequency meter which will read the slip speed in rpm over a range of 20–90 rpm from the first input system. The motor running speed is determined by subtracting the slip speed from 1800 rpm.

The range of speed that can be measured by the first input system is 1710–1780 rpm. To provide for the measurement of motor speed in the range of breakdown torque, a second input system is available which will measure slip speed from 100–450 rpm. This provides for measurement of running speed from 1350 to 1700 rpm. To do this the standard frequency is divided by a factor of five, resulting in a new standard frequency of 360 cps. Likewise, the signal frequency is divided by a factor of five. This division is accomplished by using the 12-tooth rotors in the induction alternators instead of the 60-tooth rotors. The difference frequency as measured by the frequency meter in cps must now be multiplied by a factor of five to give the slip speed in rpm. The range of speed that can be measured with this input system is 1350-1700 rpm. However, the frequency-meter error in rpm is now also multiplied by a factor of five. Neglecting line-frequency variations, the resulting accuracy of speed measurement is ±1.5 rpm or ±0.08 percent.

The third input system is incorporated so that speed may be measured without using the direct-current-generator loading device. In this section a photo-cell and a 60-hole disk (which is coupled to the motor under test and interrupts a light beam) are used to obtain the signal frequency. When this frequency is mixed with the 1800-cps standard and the difference frequency measured, the range and accuracy of the instrument is the same as with the first input system.

FREQUENCY SEPARATION

It should be noted that each input is coupled to a filter of some type. The necessity for the low-pass filter in the case of the output voltage from the low-frequency alternator is apparent as shown in Fig. 4. It can readily be seen that higher harmonics are present in the low-frequency alternators. While the oscillogram of the high-frequency alternator shows little distortion, a 30-cps component is present which requires the use of a high-pass filter. Using these filters permits a relatively pure wave shape to be used in the electronic system of mixing and separating the difference frequency. This is advisable since the operation of producing a difference frequency produces a large number of harmonics in itself and any additional frequency could complicate the filtering problem. The difference frequency is produced in this instrument by using a diode detector shown in Fig. 5. The theory of this action is quite complicated mathematically for the general case.(1) However, the equations are greatly simplified in the special case where both voltages are of the same amplitude, since a great number of the higher harmonics are eliminated.

If two voltages E_1 and E_2 having different frequencies are added, the resultant is

$$e=E_1\cos\omega_1t+E_2\cos\omega_2t$$

or

$$e=E_1\cos\omega_1t+E_2\cos[\omega_1t-(\omega_1-\omega_2)t]$$

By separating the cosine of the difference

$$\begin{aligned}e=E_1\cos\omega_1t+E_2\cos\omega_1t\cos(\omega_1-\omega_2)t\\+E_2\sin\omega_1t\sin(\omega_1-\omega_2)t\end{aligned}$$

---

(1) H. J. Reich: *Theory and Applications of Electron Tubes*, Second Edition, McGraw-Hill Book Company, Inc., New York, 1944.

Now if $E_1 = E_2$, then

$$e = E_1 \cos \omega_1 t [1 + \cos (\omega_1 - \omega_2) t] + E_1 \sin \omega_1 t \sin (\omega_1 - \omega_2) t$$

The first term of this equation indicates that it is the expression for an amplitude-modulated wave in which the carrier is one of the fundamentals while the difference frequency is the modulating frequency. As would be expected, the difference frequency can be detected with a diode rectifier. If the difference frequency is sufficiently lower than either of the fundamentals, it may be filtered out quite easily. As for the second term of the expression, it may be further expanded to give

$$E_1 \sin \omega_1 t \sin (\omega_1 - \omega_2) t = \tfrac{1}{2} E_1 \cos \omega_2 t - \tfrac{1}{2} E_1 \cos (2\,\omega_1 - \omega_2) t$$

The frequencies of both of these terms are near the original fundamental frequencies and can therefore be eliminated in the detector and the following filter. The equations require that both input voltages be equal; therefore, provisions were made in the instrument which permit satisfactory adjustment of these voltages. The oscillograms in Fig. 6 show that the wave form of the mixed frequencies does in fact appear to be an amplitude-modulated wave. The results of detection and filtering are also shown.

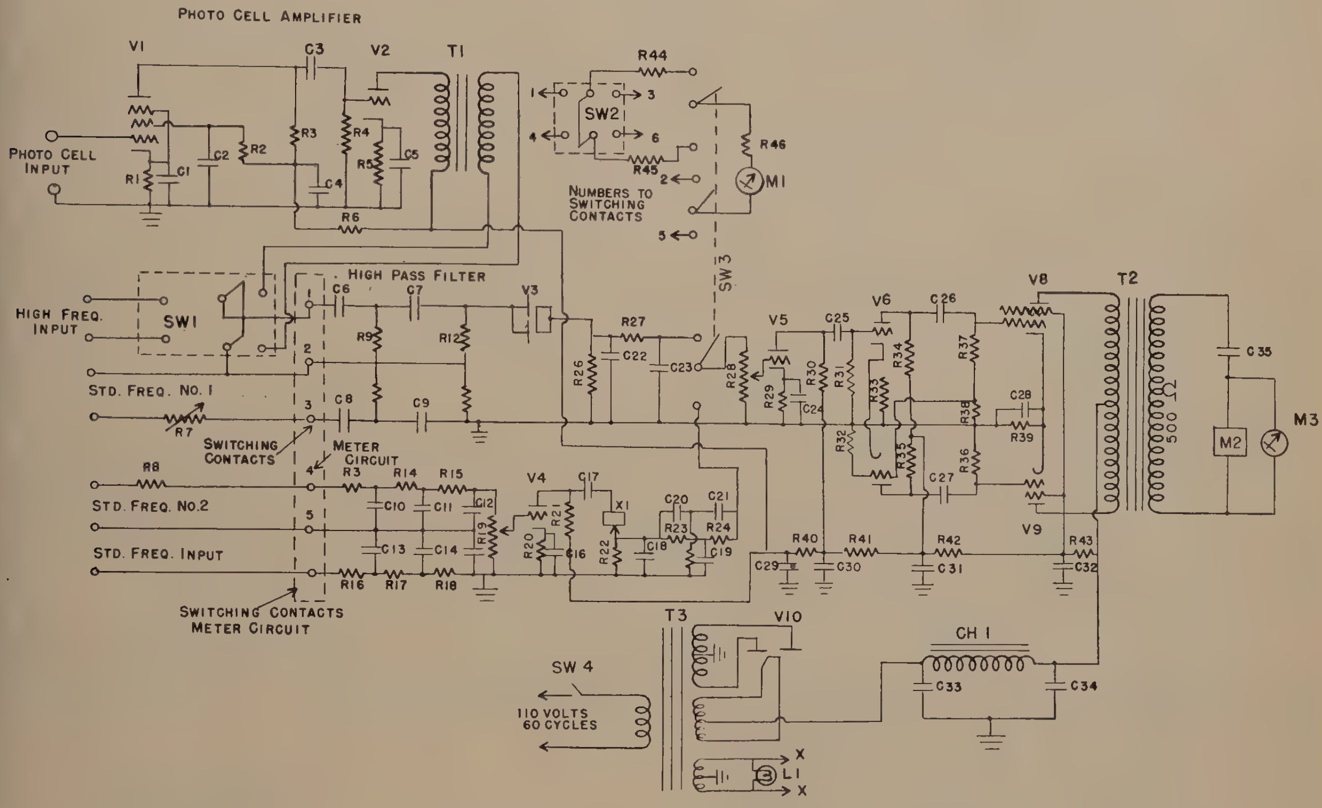


Fig. 5. Mixer, filter, and amplifier circuits of precision electronic tachometer

The connection diagram is straightforward with three input systems all coupled directly to R-C filters. It should be noticed that each input circuit has a potentiometer in one side. A voltmeter is also incorporated in the instrument, which may be selectively connected to any input circuit to permit the adjustment of the two voltages in a circuit to the same amplitude. If, instead of a detector, a square-law device has been used to produce the difference frequency it can also be shown that it is advisable to adjust the inputs to the same value. After detecting and filtering, the difference frequency is amplified and fed into the frequency meter. This part of the circuit is a straightforward amplifier with special consideration given to low-frequency response.

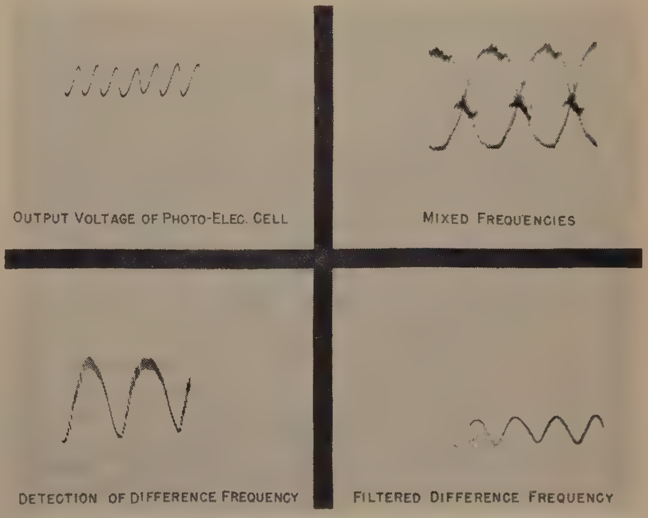


Fig. 6. Oscillograms showing wave form of mixed frequencies as an amplitude-modulated wave; also results of detection and filtering

One of more than 40 different types and sizes from 1/8" to 5/16" o.d.

Experiment in Space

with time tested components . . .

High speed movements . . .
extreme temperature ranges . . .
severe shock characteristics
Design engineers are profitably investigating
the possibilities offered by
miniature ball bearings for such applications
If you are concerned with these problems
our catalog will interest you

MPB MINIATURE *Precision* BEARINGS
INCORPORATED
KEENE, NEW HAMPSHIRE, U.S.A.

ILSCO

Connectors *Accessories*

SOLDER LUGS . . . SERVICE CONNECTORS . . . FUSE CLIPS . . . TERMINALS . . . SHADING COILS, ETC.

NEW 80-page catalog now ready showing over 2,000 Ilsco items in color.

WRITE FOR CATALOG TODAY

ILSCO COPPER TUBE & PRODUCTS, Inc.
CINCINNATI 27, O.

MEASUREMENT OF INSTANTANEOUS SPEED

(Continued from preceding page)

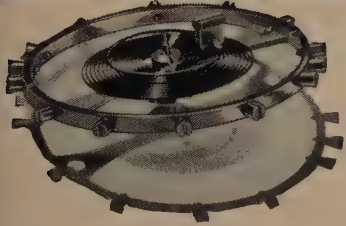
EFFECT OF LINE-FREQUENCY VARIATIONS

This type of speed measurement utilizing a synchronous motor to drive the frequency standard has a unique advantage for the special application of determining the efficiency of an induction motor. Since the efficiency of the motor under test is dependent upon the line frequency, it is desired that the measurement of efficiency should not be affected by variations in the line frequency. The inductor-alternator driven by a synchronous motor is used as a frequency standard for this type of measurement. To measure absolute running speed to a high degree of accuracy in the range of 1710-1780 rpm, either a more stable frequency standard is necessary or an extremely accurate determination of line frequency must be made. The type of frequency meter used to determine the difference frequency permits an accuracy of ±0.3 rpm in the measurement of slip speed. If the line frequency is exactly 60 cps, this permits absolute running speed measurements accurate to ±0.3 rpm or 0.017 percent since this is the accuracy of the frequency meter. However, the line frequency of some commercial power companies may vary as much as ±0.1 cps. This variation in line frequency would produce a 3-cps variation in the standard frequency and thus an error of ±3 rpm in the measurement of speed. Therefore, an accurate determination of line frequency is necessary to measure absolute speed. Instruments are available that measure line frequency to an accuracy of 0.008 percent, which results in an over-all accuracy of 0.025 percent in the measurement of speed. The disadvantage of this method is that two frequency meters must be read to determine the speed of a motor. It is therefore suggested that a tuning-fork frequency standard or crystal-controlled oscillator be substituted for the frequency standard using the synchronous-motor drive when the instrument is to be used to measure absolute speed. Frequency standards of this type are available which have accuracies of ±0.001 percent or better. With this type of standard, speed can be measured with an accuracy of ±0.018 percent.

CONCLUSIONS

Through the use of a beat-frequency method of measuring slip and the use of an expanded-scale type of indicating device, extremely accurate measurements of speed are possible. The equipment described in this article allows the measurement of instantaneous speed under certain conditions to be made with an accuracy of 0.025 percent, although the best accuracy ordinarily possible is about 0.5 percent. For an indicating device of a given accuracy, over-all accuracy in the measurement of speed may be increased with a sacrifice in the range of speed to be covered.

NACA Photo



Hair Springs and Jet Engines

. . . IMPROVED BY HIGH VACUUM

AT several famous watch factories hair springs and main springs emerge from the vacuum annealing furnace with a bright finish. Thus, cleaning operations that are costly to the manufacturer and tend to weaken the springs are eliminated.

Jet engines impose terrific heats and stresses which quickly would melt or tear apart ordinary metals. The high vacuum furnace with its freedom from oxygen and other air gases is the invaluable tool of the metallurgist to produce the metals which help make possible the harnessing of jet power.

Uses for high vacuum seem unlimited. New high vacuum techniques are constantly finding their way from the laboratory into science and industry.

Lenses, insulating paper, plastic forms, metal castings are beautifully, uniformly, and inexpensively coated by vaporizing gold, silver, chromium, and other metals in high vacuum chambers.

Substances once thought undistillable are fractionated in high vacuum stills.

Precious biological cultures are dehydrated under high vacuum to multiply four-fold the length of time they keep their potency in storage.

Manufacturers of refrigerators produce more dependable products by employing high vacuum. Electronic tubes last longer the higher the vacuum achieved in them.

It may pay you to look into high vacuum techniques. The experience of DPI research men and engineers and the DPI line of high vacuum equipment are available to all industries. We invite inquiry.

DISTILLATION PRODUCTS, INC.
Subsidiary of Eastman Kodak Company
773 RIDGE ROAD WEST, ROCHESTER 13, N. Y.
Distillers of Oil-Soluble Vitamins and Other Concentrates for Science and Industry;
Manufacturers of High-Vacuum Equipment.

H. S. Edgerly

ILLUMINATION OF SWITCHBOARD INSTRUMENT SCALES

New design providing unobstructed illumination and unimpaired scale legibility by effectively utilizing room lighting

By H. S. EDGERLY and R. M. ROWELL
Panel and Equipment Division
Philadelphia Works
Instrument Engineering Division
West Lynn Works
General Electric Company

R. M. Rowell

THE problem of providing illumination of instrument scales sufficient to enable operators to take readings with minimum eyestrain is an old one, dating back to the time when instruments and switchboards were in their infancy. In those days it was not too difficult to accomplish, for with only two or three instruments involved, lamp brackets mounted directly above the instruments provided the desired results.

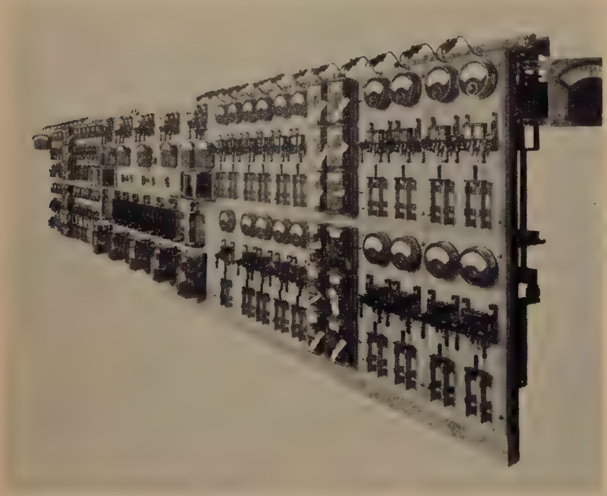


Fig. 1. Old-style d-c switchboard on which "gooseneck" lamps were used for instrument illumination

At that time, when concentrated scale illumination was desired, an instrument was available with translucent glass upon which the scale was marked. One or two lamps were located on the instrument base directly behind the scale. This form of illumination was in vogue during the days when most instruments were for direct-current service and were used mainly on railway boards. FIG. 1 shows a switchboard using lamp brackets, and FIG. 2 a board using illuminated scale instruments.

Eventually, various a-c instruments with different shapes and depths came into use. To get the best (sometimes not too good) results on these, it was necessary to use either (1) individual lamp brackets, (2) lamp troughs, or (3) unnecessarily high general illumination.

The problem of proper scale illumination was aided but not solved with the advent of the so-called streamlined switchboards where the measuring equipment is flush- or semiflush-mounted as shown in FIG. 3. Despite the improvement obtained in this respect, there still remained a constant demand for instruments with internal illumination.

FORMS OF INTERNAL ILLUMINATION

Many indicating instruments of the switchboard type are not mounted on ordinary switchboard panels, but are located on various panelboards on planes, electric locomotives, and in many other locations for the communication industry. Many of these locations are quite dark and have required special forms of illumination. For most of these cases, internal illumination of the instrument was preferred. An indication of the recognized inadequacy of switchboard instrument illumination is the large number of requests for internal illumination from all parts of the country and the increased use of such instruments as supplied on switchboards built by electrical contractors. These take various forms. The simplest, of course, is the mounting of one or more small lamps at the bottom or top of the instrument to furnish direct illumination of the scale. Such illumination is usually far from uniform and often certain parts of the scale are very dimly illuminated. A variation of this is sometimes provided by means of light slots in the side of the

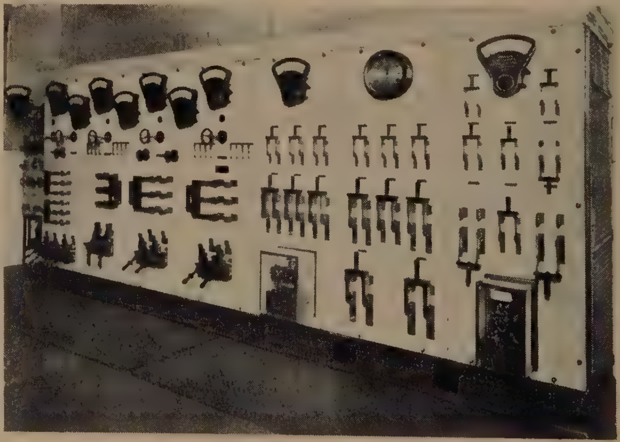


Fig. 2. Old switchboard with instruments having illuminated translucent dials

---

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

instrument cover, with lights behind the panel as in an automobile dashboard, or in an enclosure on the front of the panel. These also have the disadvantage of nonuniform illumination. The use of translucent scales, illuminated by lamps in the rear, often furnishes brighter and more uniform illumination, but ordinarily is limited to instruments whose mechanisms are small in comparison to the scale area, so that there is little obstruction between the lamp and the scale.

Edgewise illumination of engraved scales made from methyl methacrylate plastic gives excellent illumination of the engraved numerals and calibration lines, but the instrument pointer is much less brightly illuminated. Moreover, the engraving of these scales makes cost prohibitive except for very special installations.

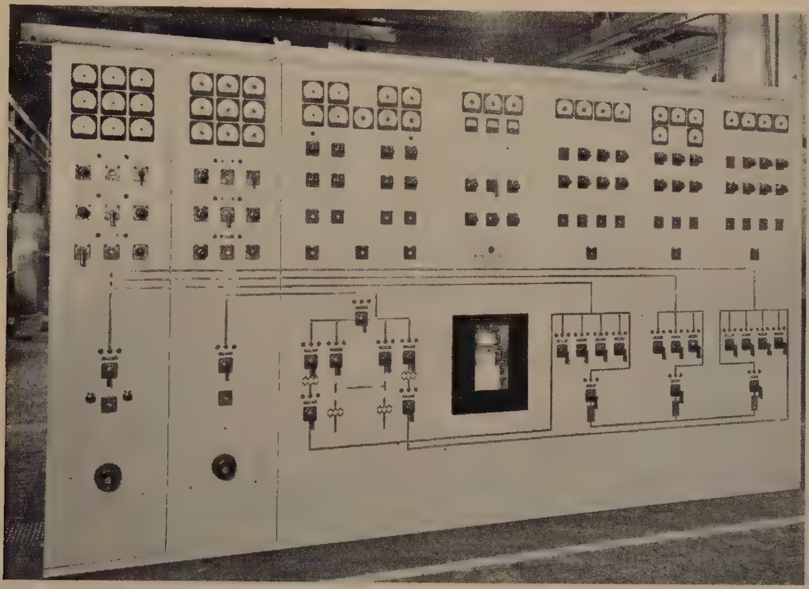


Fig. 3. Modern switchboard with semiflush-mounted instruments that are uniformly well illuminated by room lighting

Instruments having scales with numerals and calibration lines painted with fluorescent paint and illuminated by an ultraviolet (black light) source have been useful in some instances and often provide some attractive features. In this case, however, it is necessary to provide an ultraviolet light source on the switchboard panel, and these smaller light sources are often inadequate for the complete panel. There is also the tendency to eye fatigue when the instruments are watched closely. Internal or fluorescent means of illumination should be used, therefore, only as a last resort.

NEED FOR CO-ORDINATED PROGRAM OF ILLUMINATION

Within the past two years, the illumination problem has been greatly emphasized and has assumed a national aspect rather than being just a local requirement. There is a very definite and serious problem in supplying the proper kind of illumination for control rooms where switchboards and benchboards are located. The difficulty seems to be the obtaining of the proper level of illumination in the control room, with a higher level of illumination for instruments and the need to eliminate glare. The opinion prevails that the general level of illumination in the control room should be of the order of 30 to 35 foot-candles and on the instruments 40 to 45 foot-candles. To obtain these levels and eliminate glare necessitates the use of high-angle lighting on the instruments, resulting in shadows on the dials due to the overhang of the covers, which seriously affects readability. The more instruments in a vertical row, the worse the situation becomes.

It is of further interest to note that the utilities, the switchgear manufacturers, and the instrument designers are in general agreement that internal illumination is not the answer. Internal illumination is never completely satisfactory and, in addition, introduces complications such as thermal effects, additional wiring, additional resistors or transformers, and eventual lamp failures.

Horizontal as well as vertical lighting troughs have been tried with very little success.

However, the utility groups feel that they now have suitable types of light sources and fixtures, so that they can provide properly illuminated walls, ceilings, and other utilization areas with proper contrasts to adequately light control rooms and switchboards. Provision of suitable instruments to take advantage of such modern lighting arrangements is therefore necessary for complete co-ordination of illumination in control rooms.

NEW INSTRUMENT DESIGN

To meet this need, a program of co-ordinated and extensive research has been initiated in which representatives of switchgear design, instrument design, and lighting groups co-operate.

A number of lighting tests gave the impression that satisfactory scale illumination of existing instrument designs was nearly impossible. Shadows were present

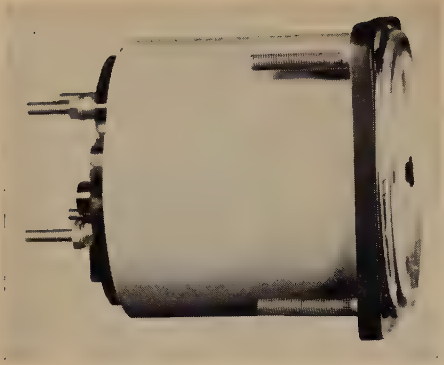


Fig. 4. Side view of new instrument, showing glass window projecting beyond bezel

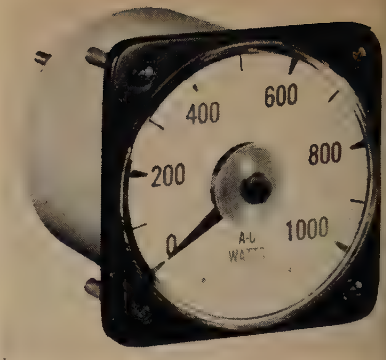


Fig. 5. Oblique front view of new instrument, showing the clearly visible, open scale

on nearly all instrument scales and the angle of illumination plus the variation of position of the instrument on the switchboard increased the nonuniformity of illumination. Because of the very nature of conventional instrument construction, the scale is usually quite deeply seated inside the case. This is due primarily to the allowance which must be made for the thickness of the glass window as well as clearance for the pointer and other mechanical parts. In the majority of cases, therefore, the cover overhang considerably shadows the readable part of the scale.

To eliminate shadows, the obvious answer was to move the scale forward on the instrument. However, the method of accomplishing this was not quite so obvious. It is still necessary to maintain clearance for the pointer and bearings and to maintain an adequate allowance for the thickness of the glass. Moreover, in many instances, particularly on direct-current instruments, the scales are mounted directly on the mechanism frame which forms a part of the electric circuit and may, therefore, be at some considerable voltage above ground, thus necessitating adequate clearance from grounded cover parts. It is also true that the dimensional tolerances required in the manufacture of molded glass are considerable and this presents a problem in fitting to a metal cover. Complete glass covers are undesirable from the standpoint of both breakage and appearance, and there is considerable prejudice against the use of transparent plastic covers because of their easily scratched surfaces and the electrostatic charges which may be built up on them.

However, these problems were all solved in the design shown by photographs in Figs. 4 and 5 and by the sketch Fig. 6. The metal part of the cover is reduced in thickness so that it projects only a short distance from the board, giving it a neater appearance. The instrument mechanism has been moved forward so that the scale is flush with the surface of the metal bezel, or slightly in front of it. The window, a round, shallow cap of molded glass, is set inside the metal cover, being held in place by molded ears which are anchored by retaining clips on the inside. This glass window then permits unobstructed illumination of the scale from any angle. All obliterating shadows are eliminated and the markings stand out very clearly as shown by the comparison in Fig. 7. Moreover, the position of the molded window between the scale and the metal bezel very effectively insulates these two parts and prevents the possibility of grounding.

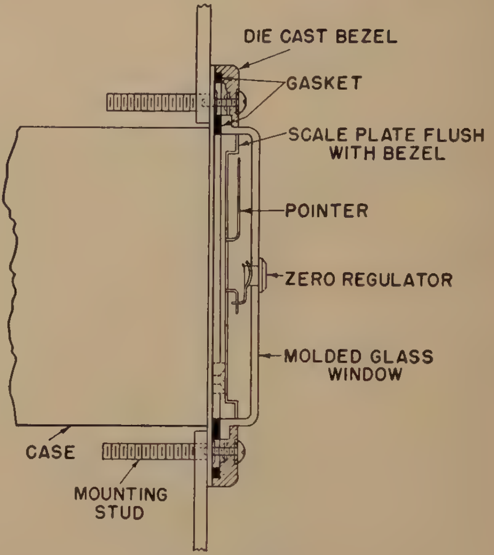


Fig. 6. Case and cover assembly of new instrument

The instrument thus can be clearly read regardless of the angle of illumination; in fact, it requires no specially designed illumination but simply a reasonably high illumination level in the switchboard room itself.

The answer to the problem of glass tolerance was found in gasketing the rounded window directly to the case. The cover bezel serves only to anchor the

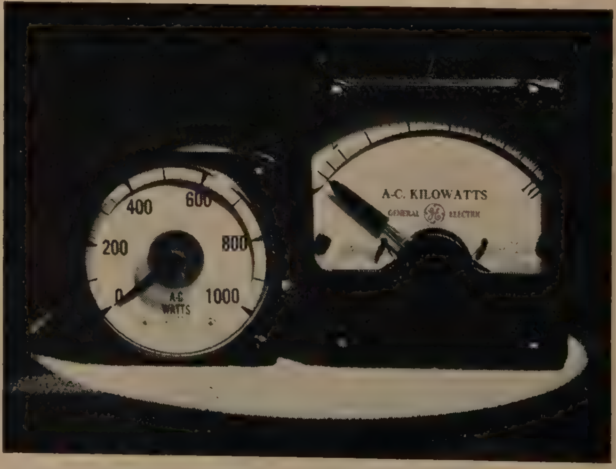


Fig. 7. Comparison of legibility of scales of new instrument and of conventional instrument, both illuminated at a sharp angle from above

molded glass window in place, and to hold it tightly against the case gasket. Even though there is a slight opening between the window and the bezel, no dust or dirt can enter the instrument.

Glare can be greatly reduced, where necessary, by the use of a light uniform etching which detracts but very little from the readability of the instrument.

CONCLUSIONS

The new instrument design has provided an answer to the challenge that instrument designers do their share in contributing to the problem of instrument scale illumination.

The important advantages of this design may be summarized as follows:

(1). It provides a simple approach to the heretofore difficult problem of scale illumination by providing adequate scale illumination with general room illumination of 30 to 35 foot-candles.

(2). With the elimination of deep shadows nearly uniform illumination of scales is obtained, thus relieving eyestrain.

(3). Special switchboard wiring is unnecessary and the problems associated with lamp failure and replacement (in internally illuminated instruments) are eliminated.

It is felt, therefore, that the design described represents an important step in the field of instrument illumination.

FILEWORTHY FACTS
on Superior Nickel
and Nickel Alloy Tubing
(Max. O.D.—⅝")
Nickel Monel†
Inconel† "K" Monel†
30% Cupro-Nickel
36% Nickel Iron (Invar)
42% Nickel Iron 52% Nickel Iron

Information on Nickel and Nickel Alloy Tubing conveniently arranged for quick, accurate reference.

The Most Complete Catalog On Small Nickel and Nickel Alloy Tubing Available.

- Comparative Physical and Chemical Properties
- Selection and Application
- Tolerance, Temper and Weight Data
- Design and "Use" Information
- Types of Superior Tubing (Seamless and WELDRAWN*)
- Time Saving Ordering and Specification Data.

Write today for your copy on your company letterhead.

For Superior Tubing on the West Coast call Pacific Tube Company, 5710 Smithway Street, Los Angeles 22, California, ANgeles 2-2151

THE BIGGER NAME IN SMALL TUBING Superior

SUPERIOR TUBE COMPANY
2040 Germantown Ave.
Norristown, Pennsylvania

*Reg. U. S. Trademark. Superior Tube Company
†Reg. U. S. Trademark. The International Nickel Co.

See our tubing display booth No. 2527 at the 31st National Metal Exposition, October 17th to 21st, Cleveland, Ohio

NEW MIDGET RELAYS

good for all vibration conditions

Ward Leonard's new Bulletin 110 Relays have unusually heavy contact pressures . . . good proportioning of contact masses and springing . . . and semi-knife-edge bearings assuring long trouble-free service under adverse conditions.

Generous sized contacts provide higher contact ratings than found in most midget relays. Available up to 3-pole double throw. Write for Bulletin 110. Ward Leonard Electric Co., 62 South Street, Mount Vernon, N. Y. Offices in principal cities of U. S. and Canada.

WARD LEONARD ELECTRIC CO.
Result-Engineered Controls
RESISTORS • RHEOSTATS • RELAYS • CONTROL DEVICES

DO YOU KNOW?

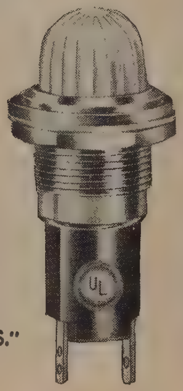
—that a PILOT LIGHT CAN IMPROVE YOUR PRODUCT . . . add attraction—safety—service?

Ask DIALCO
— what lamp to use
— how to use it
— what it will do
— what it will cost

THIS MAY BE THE ONE
Designed for low cost NE-51 Neon
• Built-in Resistor • Patented
• U/L Listed • Rugged
Catalogue Number 521308 — 997 for 110 or 220 volts.

SAMPLES
for design purpose
NO CHARGE

NEW! Write for the "HANDBOOK OF PILOT LIGHTS."
Write us on your design problems.



Foremost Manufacturer of Pilot Lights
The DIAL LIGHT COMPANY of AMERICA
900 BROADWAY, NEW YORK 3, N. Y.

Reflecting the experience, resources and skill of the world's largest producer of fine ball bearings.

NEW DEPARTURE

BALL BEARINGS

NEW DEPARTURE · Division of GENERAL MOTORS · BRISTOL, CONNECTICUT

What's the Big Idea?

Every once in a while, somebody takes a jaundiced squint at Big Business and howls: "Break it up!"

It isn't always a Socialist. Nor even a Communist. This sniper at Big Business may not be subversive at all.

Charge him with being opposed to free enterprise and, likely as not, he'll raise a righteous holler that he's as good an American as you are.

He may well be. But his pet peeve is — Big Business.

He forgets that Big Business symbolizes the growth and achievement that our American free enterprise encourages.

He overlooks the fact that a business must earn the continuing confidence and good will of a satisfied buying public to grow big and stay big.

He ignores the wonderful truth that under free enterprise any business, however small, has the opportunity to grow big.

He shrugs off the benefits that Big Business spreads around. Benefits to workers in good pay. Benefits to consumers in lower prices. Benefits to other, smaller businesses that owe their existence to the many, continuous and tremendous needs of Big Business.

SHERRON ELECTRONICS CO.

Division of Sherron Metallic Corporation

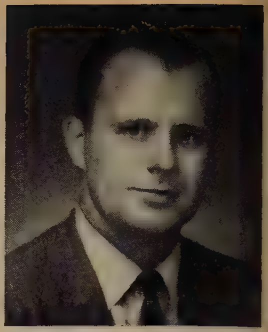
1201 FLUSHING AVE., BROOKLYN 6, NEW YORK

MANUFACTURERS OF ELECTRONIC DEVICES AND SHEET METAL FABRICATION

Frank J. Studer

SPECTRORADIOMETRY

Basic principles. Widespread use of fluorescent lamps necessitated the development of new recording instrument for the rapid determination of spectral distribution of light sources



W R Jacobson

By DR. F. J. STUDER and W. R. JACOBSON
Research Laboratory
General Engineering and Consulting Laboratory
General Electric Company

A SPECTRORADIOMETER is an instrument with which it is possible to tell quantitatively how much of each color is present in the light radiated by a source. It analyzes a light beam into its spectrum, and measures the energy flow in each wavelength band. This makes it possible to specify the color of the light beam by plotting a spectral-energy-distribution curve—relative energy against wavelength. If the light has come directly from the source with no intervening reflecting or absorbing medium, this curve will give the energy distribution of the radiation from the source itself, and from it can be determined the I. C. I. color co-ordinates of the source.

A spectroradiometer can be designed for point-by-point measurement, in which instance readings must be taken at frequent intervals on the wavelength scale, or it can be a recording instrument which will draw the energy-distribution curve automatically. In this article the basic principles of spectroradiometry will be briefly presented and, in particular, a new recording instrument will be described.

Before the widespread use of fluorescent lamps, the need for an instrument to give a rapid determination of spectral distribution of light sources was not strongly felt. With incandescent tungsten lamps, the color distribution in a clear lamp is solely a function of the temperature at which the lamp is operated. This temperature is determined largely from considerations of efficiency, which require the highest temperature at which the filament will have reasonably long life. The spectral distribution is well known at any temperature from carefully performed laboratory measurements; thus to obtain the color distribution it is necessary to measure only the temperature of the filament with an optical pyrometer or other device, and then to find the energy values from easily accessible handbook tables.

If the light from the tungsten filament is altered by a colored bulb or a filter, or by reflection from a colored surface, the characteristics of the transmitted or reflected light can be determined quickly and with high precision (from the spectral transmission or reflection curves obtained) using one of the automatic recording spectrophotometers which are available. The reflection

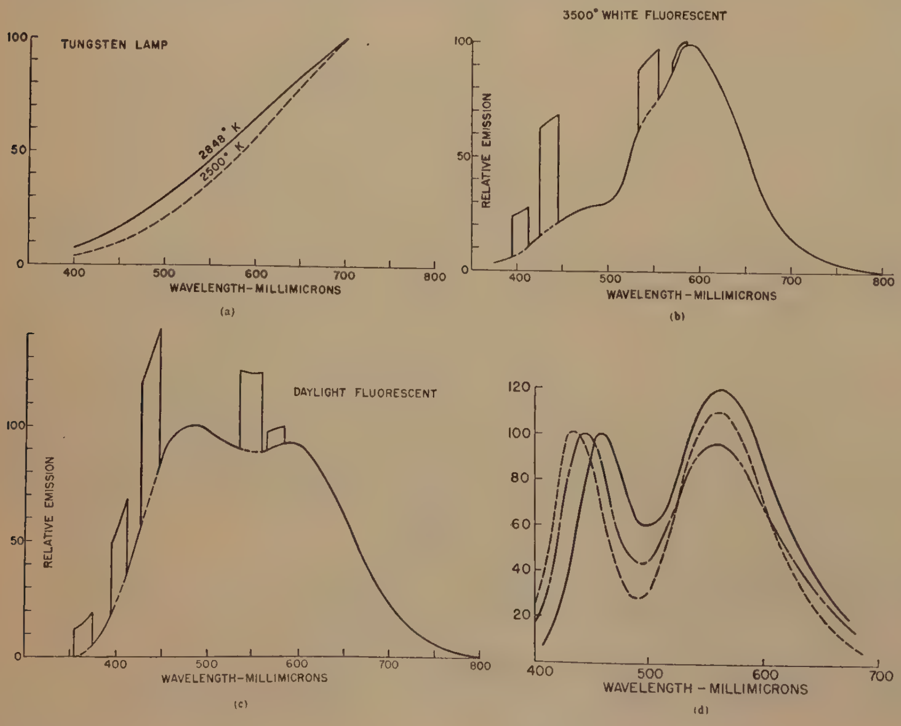


Fig. 1. Typical spectral-emission curves
(a): Tungsten filament lamp at 2848K and 2500K
(b): 3500-deg white fluorescent lamp
(c): Daylight fluorescent lamp
(d): Television-tube screens

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—Editor

or transmission curves, together with the emission curve from the tungsten lamp, permit the determining of the spectral nature of the light beam in each instance.

With the development of fluorescent lamps, there became available light sources with practically an infinite variety of colors in contrast with the relatively constant tungsten lamps. It is not possible to find the spectral distribution for these fluorescent materials in a handbook. Consequently, each one must be analyzed independently by direct measurement, and a much greater number have already been discovered than could be feasibly measured by employing the time-consuming point-by-point method. For this reason it became almost imperative to have a rapid-acting recording spectroradiometer, such as that described in this article.

Consideration of the distribution curves of some typical light sources will serve to emphasize the need for such an instrument. In Fig. 1 are shown spectral curves for (a) tungsten lamps in the normal operating temperature range, (b, c) two common fluorescent lamps, and (d) typical television-tube screens.

It will be noted that the change in spectral distribution of a tungsten lamp with operating temperature is gradual and uniform. With fluorescent lamps, on the contrary, almost any change can be brought about by changing phosphors.

A portion of the light from the mercury discharge in the fluorescent lamp is, of course, transmitted by the phosphor coating of the bulb, and these mercury lines are present in the emitted light. Actually, they are confined to extremely narrow wavelength bands, but it has become a matter of convention to indicate them as though the energy were spread a wavelength band (20 millimicrons wide) centering on the line.

In many instances, the character of the light emitted by the phosphor itself is greatly affected by various factors in its manufacture such as the conditions of firing, the amount of activator, and the relative amounts of the basic constituents.

The basic procedure in determining the spectral-energy distribution of an unknown source is to compare the source with a standard lamp whose calibration is made in terms of the radiation from a black body at a given temperature. Tungsten lamps of a given color temperature are obtainable from the National Bureau of Standards or from the Standardizing Division of the General Electric Lamp Department at Nela Park.

POINT-BY-POINT METHOD FOR DETERMINING SPECTRAL DISTRIBUTION

A method for point-by-point determination of the spectral distribution of diffuse sources is indicated in Fig. 2. The procedure followed will be outlined briefly. The entrance slit of the spectroscope receives alternately light from source X being measured and from a standard lamp K (the latter reflected from a smoked magnesium-oxide surface R). This is achieved by means of a shutter S and the disk R which are so arranged that when the light from X is incident on the spectroscope slit, the shutter S cuts off the light of the standard lamp, and when R is in place it prevents the lamp X from shining on the slit. The light in a given wavelength band, determined by the setting of the exit slit E, falls on the cathode of the photomultiplier P on which a d-c voltage of 50 to 100 volts per stage is maintained by means of a well-regulated supply. The use of a photomultiplier avoids the necessity for an extremely high-gain amplifier which would be necessary with an ordinary photocell.

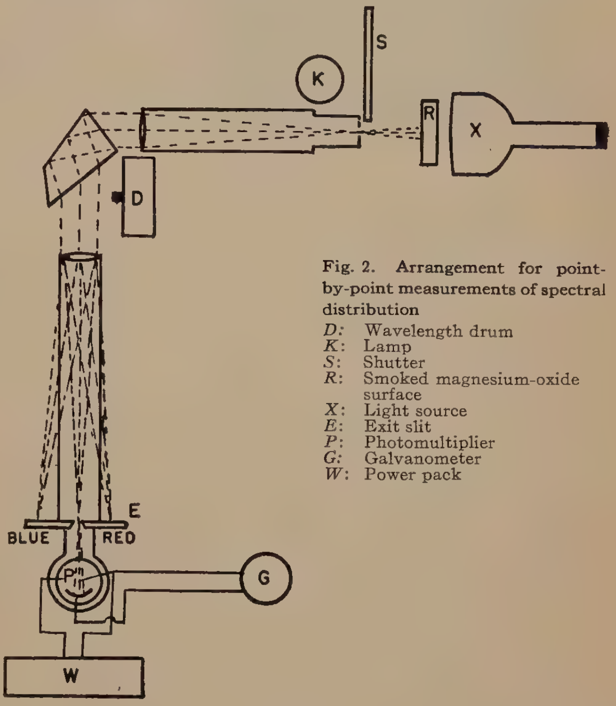


Fig. 2. Arrangement for point-by-point measurements of spectral distribution

D: Wavelength drum
K: Lamp
S: Shutter
R: Smoked magnesium-oxide surface
X: Light source
E: Exit slit
P: Photomultiplier
G: Galvanometer
W: Power pack

The voltage on the multiplier is adjusted by means of the power pack W to give deflections of the galvanometer G of suitable magnitudes at the wavelength region being studied as set by the wavelength drum D. Then, the galvanometer deflections d_K are taken for the standard lamp and d_X for the unknown. The relative energy of the unknown can be computed simply as $\frac{d_X}{d_K} R$, where R is the emission of the known lamp. This is based on the assumption that the reflectance of the MgO block is 100 percent; if higher accuracy is desired, the actual reflection factor must be included. The light from the standard lamp is reflected from a smoked MgO surface rather than shining it directly on the slit, to insure that the aperture of the spectrometer will be filled with light in the same way that it is from the unknown source.

RECORDING ARRANGEMENT FOR SPECTRAL CURVES

In view of the growing need for quickly determining spectral distribution curves, a recording spectroradiometer (Fig. 3) was developed in the Research Laboratory. One of these spectroradiometers has been

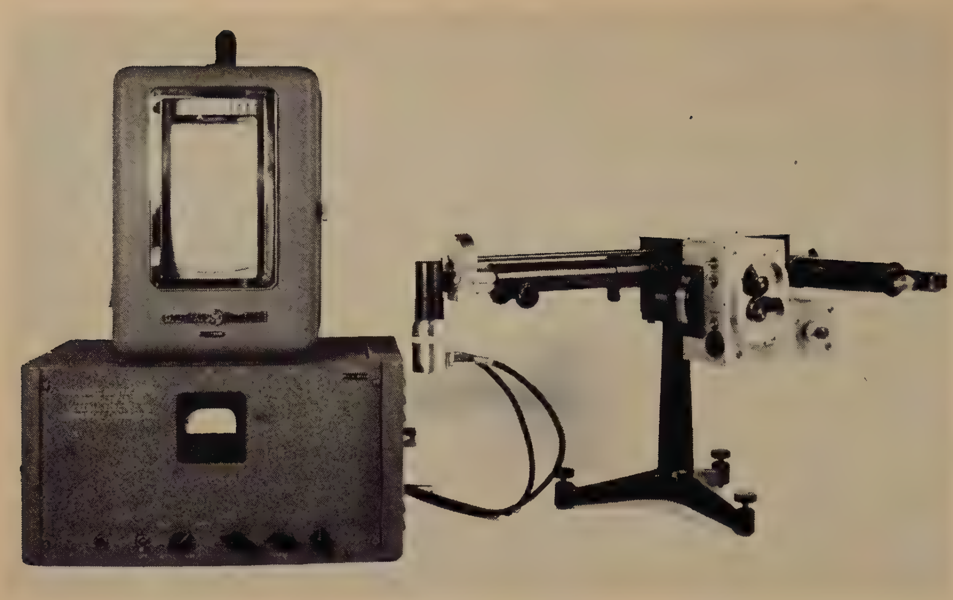


Fig. 3. Recording spectroradiometer using constant-deviation prism spectrometer

in active use for several years at Nela Park and another in the Research Laboratory. The dispersion element is a conventional constant-deviation spectrometer whose wavelength drum is turned by a 6-watt synchronous motor, through a double cam so designed that the spectrum sweeps past the exit slit at a constant-wavelength rate. This means that the length of time required to turn through a given wavelength band is the same in all parts of the spectrum. The cam arrangement is shown in Fig. 3.

The receiver is an electron multiplier of relatively high response to red light. Because the cell is operated on d-c power, its operation is essentially unaffected by the frequency of the light source. Voltage for the dynodes is obtained from a regulated RF power supply whose output can be varied from 400 to 1000 volts. The output of the photomultiplier is amplified by a conventional low-drift circuit, and fed into a photoelectric recorder which draws the spectral-energy-distribution curve. The recorder chart is driven by a synchronous motor which is turned on by the same switch that controls the wavelength motor. The chart, therefore, turns in synchronism with the wavelength drum. Thus, the wavelength scale on the chart is linear. The spacing on the wavelength scale is determined by the speed to which the record chart is geared and the speed at which the wavelength drum turns.

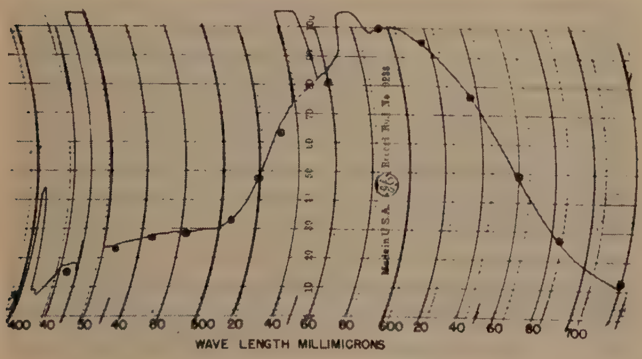


Fig. 4. Spectral curve for white fluorescent lamp taken with prism instrument shown in Fig. 3. Plotted points are values taken for same lamp with double-quartz monochromator at Nela Park

In order that the output of the photocell may be proportional, at all points in the spectrum, to the energy in a constant-wavelength band radiated from the source, compensation must be made for three factors:

(1). Variation in response of the photocell with wavelength

(2). Increase in dispersion when going from red to violet

(3). Absorption in the prism and lenses of the spectrometer.

This necessary compensation is accomplished in a simple but effective manner by means of a disk of varying radius which rotates just in front of the exit slit. This disk is designed to cover the proper amount of the exit slit at each wavelength to compensate for the three factors mentioned. The data for constructing the compensator are obtained by means of a tungsten lamp of known color temperature, the light being reflected from a diffuse reflector, such as a block smoked with magnesium oxide, or a piece of vitrolite. The distribution curve drawn by this instrument for a white fluorescent lamp is shown in Fig. 4. The points shown are those determined by Dr. B. T. Barnes of Nela Park for the same lamp using a large quartz double monochromator.

APPLICATION TO EXCITATION AND ABSORPTION STUDIES OF PHOSPHORS

The recording arrangement of the instrument can be adapted to any type of spectrometer. If a concave reflection-type diffraction grating is used, two notable advantages are realized. First, the dispersion is practically constant, which eliminates the necessity for a nonuniform drive system; this also means that the avelength band transmitted by the exit slit is nearly onstant throughout the spectrum. Second, the wave- ngth range in which it is possible to work is not mited to the region of glass transmission but extends aroughout the entire range of sensitivity of the photo- ell, which may conveniently be from 200 to 800 illimicrons.

One drawback of a grating instrument is that the cond-order ultraviolet in the spectrum overlaps the rst-order visible, but this can be met by introducing a appropriate filter when working in the visible region.

A diffraction grating can be used not only for the etermination of emission spectra of fluorescent aterials but also for absorption and excitation charac- ristics of these materials. The nature of the absorp- on can be studied by comparing the light reflected by e phosphor sample with that reflected from a smoked agnesium-oxide surface. Samples of the phosphors bout 3 cm diameter and 1 mm thick) are prepared in allow containers and so placed in a mount that they n be brought successively into position in front of the trance slit. The sample is then illuminated with the ght from a hydrogen discharge lamp which gives a ntinuous spectrum extending beyond 200 millimi- ons in the ultraviolet, and the spectral curve of the flected light is recorded. This, when compared with e corresponding curve for MgO, will show the sorption regions of the phosphor.

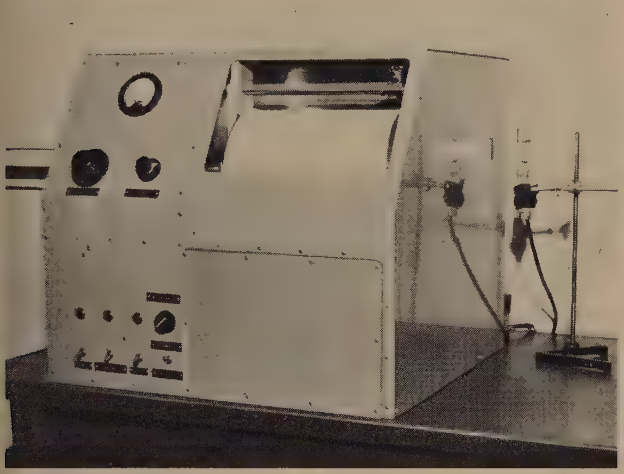


Fig. 5. Recording spectroradiometer showing grating-type instrument developed for industrial applications

It is possible also with this instrument to locate the citing wavelength for which the phosphor shows the ost efficient response. This is accomplished by coating small glass slide with a thin layer of phosphor and acing it just behind the exit slit, in front of the photo- ll. If the entrance slit of the spectrometer is now uminated directly by the hydrogen lamp, the phos- or will be swept progressively through the continuous ectrum as the instrument is operated; the response rve of the photocell will indicate the amount of fluorescent light produced at each wavelength. This knowledge is particularly important in finding new phosphors for lamps, since any phosphors useful in our present lamps must respond efficiently to the 253.7 millimicron line of mercury.

SPECTRORADIOMETER DESIGNED FOR INDUSTRIAL USE

The General Engineering and Consulting Laboratory has developed the diffraction-grating type of spectroradiometer for use in industrial laboratories. The developmental form of the device is shown in Fig. 5.

Description

The block diagram (Fig. 6) shows schematically the monochromator, photometer, recorder, and power supply of the developmental spectroradiometer built by the General Engineering and Consulting Laboratory.

Monochromator. The monochromator employs a one-meter replica diffraction grating of 15,000 lines per inch in a Wadsworth or parallel-beam-type mounting. Radiation passing through the entrance slit falls on a collimating mirror and is reflected to the grating, which is mounted directly above the center of rotation of the monochromator arm. The phototube housing is mounted on a sliding portion of this arm in such a manner that the distance from the grating to the exit slit can be varied by means of a cam so that the image of the entrance slit is always in exact focus at the exit slit. Thus, to scan the spectrum from 200 to 800 millimicrons, the monochromator arm is so rotated that the angle of incidence of the parallel beam striking the grating is varied from 6.8 deg to 28 deg. A Corning 3060 filter is permanently mounted in the 400–800-millimi-

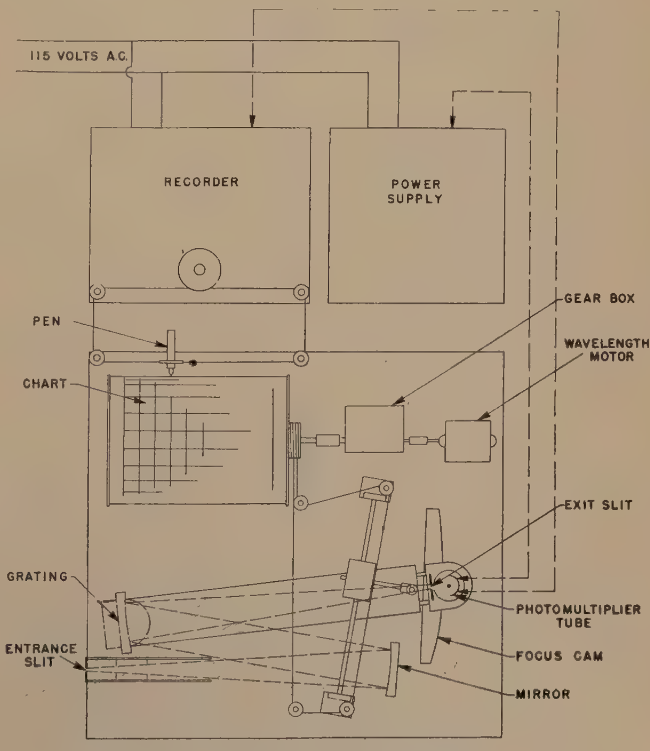


Fig. 6. Schematic diagram of spectroradiometer shown in Fig. 5

cron portion of the spectrum to filter out the 200–400-millimicron second-order spectrum (FIG. 7).

The recorder drum is directly coupled to the monochromator arm by means of a cable drive which insures synchronism between the recorder and the monochromator. A variable-speed motor drives the recorder, making it possible to scan the complete spectrum in a period of time which can be varied from one to ten minutes.

The entrance and exit slits are matched pairs which are easily and quickly changed to enable the operator to get the resolution desired. At present, slits giving bands of 0.85, 2.1, 4.2, and 8.4 millimicrons are used.

Photometer. The primary element which makes this type of instrument practical is the photomultiplier tube which has come into wide use during the past few years for measuring extremely low light levels. The 1P28 tube is used because of its sensitivity to the ultraviolet, as well as to the visible spectrum.

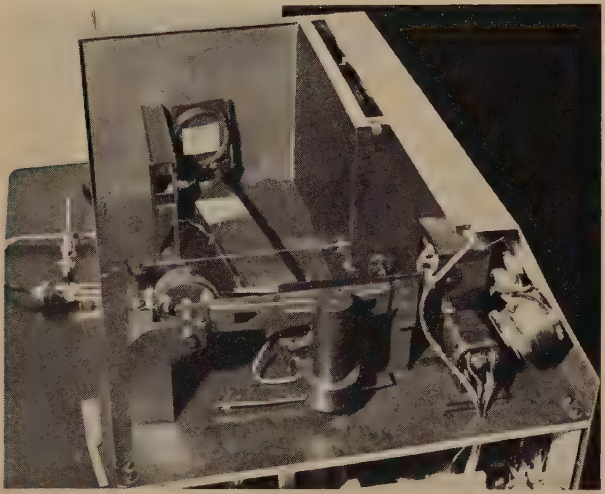


Fig. 7. Interior view of spectroradiometer showing monochromator arm, calibration mask, and photocell housing

Recorder. For optimum stability, the photomultiplier is operated with its maximum output of only one microampere. This current is measured on a modified Leeds and Northrup Speedomax recorder mounted inside the instrument case. A flexible cable drive from the recorder positions the pen carriage along the chart drum. This drum accommodates graph paper 9⅞ by 24 in., exclusive of borders, marked with a photometric scale of 0–100 relative energy units and a wavelength scale of 200–800 millimicrons. A zero adjustment is provided to compensate for the phototube dark current. FIG. 8 shows typical curves drawn for a mercury-cadmium lamp using 0.85-millimicron slits. The two curves are for the same source and are drawn with the instrument set at two different sensitivities.

Power supply. To attain a several-hundredfold range in sensitivity, advantage is taken of the fact that the output of a photomultiplier tube varies nearly logarithmically with voltage. The phototube voltage from the d-c supply, regulated to better than 0.2 percent can be varied between 0 and 1000 volts by a panel-mounted control. A 67.5-volt battery supplies the voltage between dynode and plate of the photomultiplier tube.

Calibration. As described previously, the current output of the photomultiplier at a given wavelength is a function of the light source, the transmission of the optical system, and the response of the phototube. Because the latter two are not constant with wavelength, some corrections must be made so that the recorder will draw a straight horizontal line for a source that radiates equal energy at all wavelengths.

To determine what this correction is, the output of the photomultiplier is recorded when it receives radiation from a source whose energy distribution is known. The difference between the curve drawn and the known curve is the correction to be made. This can be accomplished by placing a properly shaped mask in front of the exit slit so that the effective height of the slit is raised as the phototube passes through the spectrum behind the mask. Thus, the correction is accomplished with no additional moving parts. This mask can be seen in FIG. 7.

To calibrate this instrument, two standard sources are used: (a) a Uviarc mercury lamp or a hydrogen lamp for the ultraviolet spectrum, and (b) a tungsten lamp for the visible spectrum. These lamps, operating under controlled conditions, have been calibrated by the Standards Division, General Electric Lamp Department, Nela Park, Cleveland. The procedure in calibrating an instrument is to vary the height of the exit slit by means of a knife edge attached to a micrometer. At selected points in the spectrum, the knife edge is adjusted until the recorder reads the correct value. Micrometer readings taken at these points give the data required for cutting a permanent mask which, when properly mounted in the instrument, effectively varies the height of the exit slit as the monochromator arm rotates. The prism-monochromator-type spectroradiometers calibrated in this manner have retained their calibration after more than two years of operation.

Features

At this point it is desirable to list for convenience the more important capabilities of the equipment.

(a). Compact unit—easy to operate

(b). Ultraviolet and visible spectrums recorded on chart 9⅞ by 24 in.

(c). Rapid operation—complete spectrum can be scanned in as short a time as one minute

(d). Resolution—variable band pass of 0.85, 2.1, 4.2, and 8.4 millimicrons used at present

(e). Sensitivity—variable voltage on photomultiplier gives several hundredfold range of sensitivity

(f). Precision—curves can be reproduced with an accuracy of ±1 percent

(g). Useful for measuring spectral sensitivity of photocells. Using a standard source and by modifying the instrument, the spectral distribution of photocells can be recorded.

APPLICATIONS

Basic Study of Fluorescent Materials

The principal field of application of the spectroradiometer is the study of fluorescent materials. When a new series of phosphors is discovered in the laboratory, the color distribution can be readily measured, and a rapid exploratory study made of the effect of the many variables involved in the manufacturing process. In addition to its importance in practical applications, a knowledge of the spectral distribution plays a significant role in the theoretical interpretations of the behavior of phosphors. The instrument can also be adapted, as has been pointed out, for absorption and excitation studies of phosphors.

Standardization and Control of Fluorescent Lamps

In the standardization and control of the color of fluorescent materials, the spectroradiometer is an essential instrument; with it, it is possible to discover very quickly just what is happening to the spectrum of a lamp or phosphor when a change in color is noted. This is impossible by visual observation; although the eye can detect very small color differences, it cannot make any analysis of the change in the spectral distribution which is responsible for the changed color sensation. For several years now, an instrument of the prism type previously described has been extensively used by the Standardizing Division of the Lamp Department at Nela Park for comparative measurements on both lamps and phosphors. The Research Laboratory also makes continual use of one in its basic studies of phosphors.

Standardization of Television-tube Screens

In the standardization which is developing in the television-picture-tube field, a spectroradiometer is becoming an essential piece of equipment. The screen of the television tubes being manufactured now consists of a blend of two phosphors with peaks at approximately 440 and 560 millimicrons. The proportions are such as to give a "white" whose color co-ordinates are in the neighborhood of those of a black body at 6500 K. The relative heights of the emission peaks of the two phosphors depend primarily upon the proportionate amounts of the phosphors and the method of depositing the screen. If the color is off, the spectral distribution curve will tell exactly where the trouble arises. As the tolerances for these tubes become closer, the only method for maintaining them will be by spectroradiometric analysis. This will become increasingly true as color television is developed.

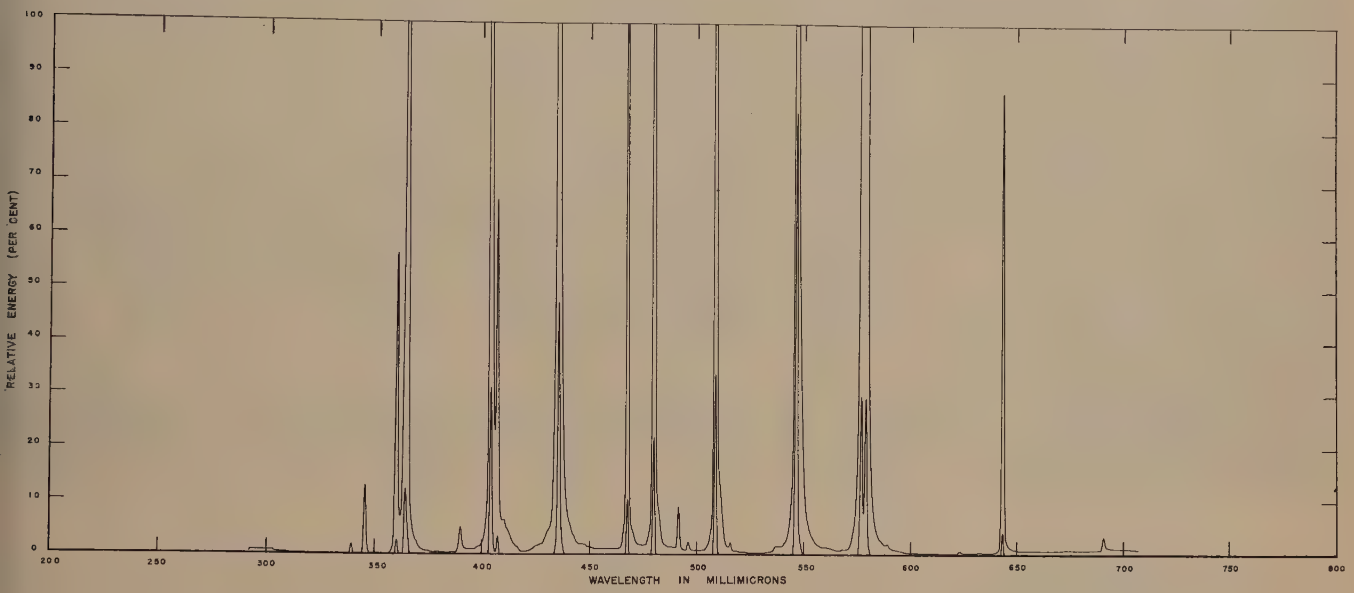


Fig. 8. Two curves of a mercury-cadmium arc spectrum drawn at different sensitivities with slits at 0.85 millimicrons

Spectral Analysis of the Light Emission from Electric-arc and Discharge Lamps

The spectral emission of any light source can be determined much more quickly by taking a curve with this instrument than by photographing the spectrum. This makes it possible to follow easily the changes in emission which occur when operating conditions are altered. The instrument is not adapted for general spectrographic analysis, however, because it is not designed for high resolution of spectrum lines.

REFERENCES

(1)"An Automatic Recording Spectroradiometer for Catholuminescent Materials," by V. K. Zworykin, *J.O.S.A.* 29, 84-91 (1939).

(2)"A Method for Measuring Energy Distribution of Low Brightness Light Sources," by F. J. Studer, *J.O.S.A.* 37, 288-291 (1947).

(3)"A Method for Automatically Plotting Spectral Energy Distribution of Luminescent Materials," by F. J. Studer, *J.O.S.A.* 38, 467-470, (1948).

(4)"A Combination Phosphorometer and Spectroradiometer for Luminescent Materials," *Trans. Electrochemical Society.* 91, 20 (1947).

* SUBMINIATURE IN SIZE
* GLASS-TO-METAL HERMETIC SEALS
* STANDARD RATINGS TO 600 V. D-C
SPRAGUE
Dependable!

SUBMINIATURE PAPER CAPACITORS
Hermetically Sealed in Metal Cases

Sprague Subminiature Paper Capacitors represent the latest development in the trend toward smaller components with characteristics that are at least equal and often superior to their larger counterparts.

The unusually small size of these paper capacitors is a direct result of new techniques, materials and processes developed through painstaking research.

Sprague Subminiature Paper Capacitors give trouble-free performance under the most exacting electrical, temperature and humidity conditions.

Glass-to-metal solder-sealed terminals assure positive hermetic closure with maximum arc-over clearance to metal cases. Subminiature capacitors are available with either grounded or insulated sections using various capacitor impregnants, so as to best meet *your* individual circuit requirements for physical size, insulation resistance, operating temperature and other factors.

Complete details of Sprague Subminiature Paper Capacitors are given in Bulletin No. 213. Please write for your copy on company letterhead.

SPRAGUE

SPRAGUE ELECTRIC COMPANY
North Adams, Massachusetts

PIONEERS IN
ELECTRIC AND ELECTRONIC DEVELOPMENT

HOW TO TEST FOR LEAKS RELIABLY, QUICKLY, AND AT LOW COST

The considerations to be observed for obtaining the maximum service from the halogen-type leak detector in factory testing of products by individual and group testing methods

By J. R. NEFF
Pittsfield Works Laboratory, General Electric Company

John R. Neff

RELATIVELY little information has been published on specific methods of applying the halogen type of leak detector and on the testing techniques necessary for obtaining the greatest benefits through its use.

The purpose of this article is to provide that information so that, by proper application and manipulation of the device, the testing costs can be reduced and output materially increased, as demonstrated by a number of applications of the detector in the Pittsfield Works of the General Electric Company during the past year.

DEFINITION

Basically, all materials leak or will pass some minute amount of gas or liquid under certain conditions. It is entirely conceivable that modern leak-testing equipments can be constructed that will detect even microscopic leaks.

The definition of a leak becomes more and more difficult to formulate when considered in terms of detection by the use of modern highly sensitive testing facilities. It may be necessary to reject one product as leaking, whereas another product may be entirely satisfactory although showing an equal leak.

In view of these wide variations in the definition of a leak, it is no longer sufficient for the design or manufacturing engineer to make a statement to the effect that his product must not leak. He must qualify his statement to include the value of the maximum allowable leak. It may be in terms of basic values or may be a general statement of leak conditions after definite periods of time and under specific temperatures and pressures. For example: "The maximum leak in the tank must not permit the escape of more than one tenth of an ounce of Freon gas in a year's time with the gas pressure held at ten pounds per square inch"; or "The tank must be able to hold transformer oil without any visible signs of leaking for a period of one week when the tank is subjected to an internal pressure of thirty pounds per square inch and to a temperature of one hundred degrees Centigrade."

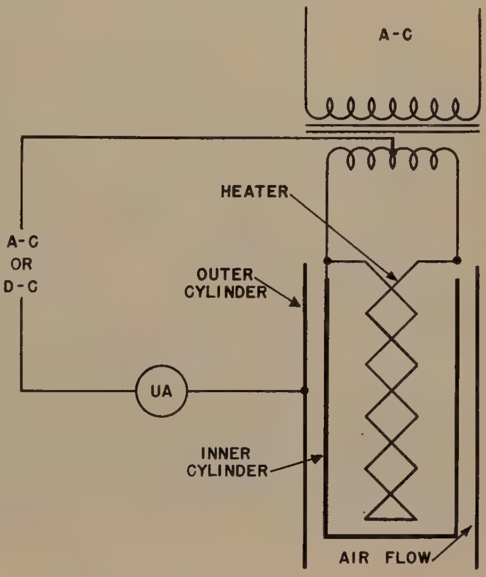


Fig. 2. Schematic diagram of the basic circuits used in the leak detector that is shown in Fig. 1. *UA* is the indicating instrument. It may be replaced with either earphones or an amplifier and speaker system

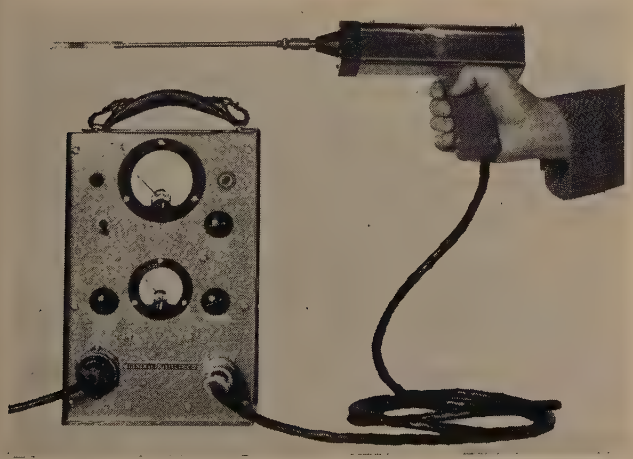


Fig. 1. The leak detector by means of which the time and cost of testing for leaks can be greatly reduced and reliability of detection greatly increased. The control unit is at the left, and the detector unit with probe is shown at the right

A statement of allowable leak size should be based on actual requirements because too stringent a limit will increase manufacturing and testing costs and, hence, product costs. On the other hand, a statement that will permit the passing of a defective unit will increase replacement costs and result in complaints.

The application engineer, fortified with the thorough knowledge of the design engineering requirements and with the manufacturing engineer's production needs, is in position to properly analyze the entire measurement field and to choose, from the many types of testing

---

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

equipments, the one best adapted to the application. The type of leak detector shown in FIGS. 1 and 2 has, in our experience, been found to be the most versatile from the standpoint of sensitivity and ease of application to production testing.

THEORY

The operation of the leak detector has been adequately presented elsewhere⁽¹⁾ and will not be described in this article beyond calling attention to the fact that it responds to the various halogen vapors.

In using this leak detector, it is necessary to inject one of the halogen vapors into the product to be tested. Freon 12 and sulphur hexafluoride have been found to be the easiest to handle. Any minute amount of the halogen vapor that escapes can be indicated by the detector. The sensitivity of the type of detector in FIG. 1 is such that it will indicate any leak that will permit the loss of one hundredth of an ounce of Freon gas in a year. A leak that takes a week to pass sufficient transformer oil to moisten a powder coating enough to show a discoloration the size of a pin head, when the oil is held at one hundred degrees Centigrade temperature and internal pressure of thirty pounds per square inch, can be detected almost instantly as the detector element passes the leak area.

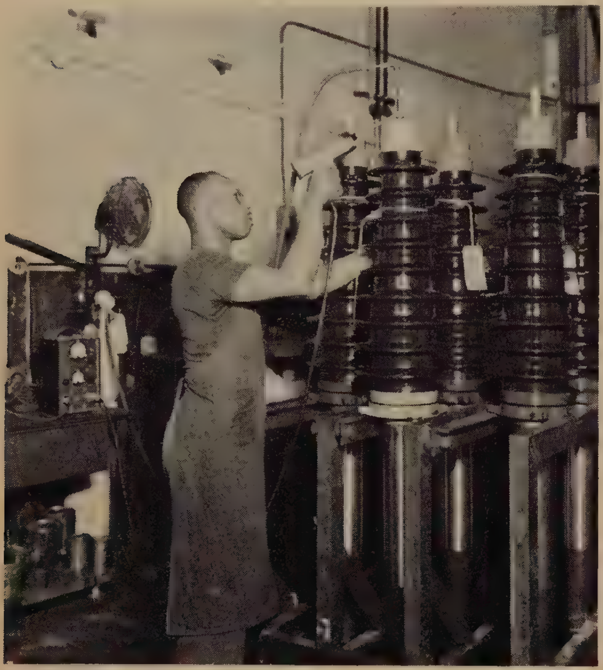


Fig. 3. A typical example of the use of the leak detector as utilized in testing large or varied apparatus by the exploratory method

APPLICATION

The detector can be handled by factory testmen. Actual use, in the factory, has indicated that they do not encounter difficulties in operation but actually find it easy to operate and not tiring to the eyes. Since it can be made to indicate a leak, by either visual or audible means, many of the usual errors are eliminated.

Each individual leak detection application will vary to some extent, either in sensitivity requirements or in physical set-up, and will therefore require its own technique. The over-all field can be divided into three general classifications, where actual set-ups, in each class, will require substantially identical over-all engineering.

Large and Varied Apparatus

Under the classification of large and varied apparatus might be listed transformer tanks, refrigeration systems, high-voltage bushings, coupling capacitors, pipe lines, or any equipment where the actual testing time is not a limiting factor, although still important.

A testing set-up for this type of equipment is relatively simple, since the chief precaution is that of making certain that the testing is carried on in an ambient that is sufficiently free of halogen vapors. In many instances, an exploration of the available floor space will indicate a location that is free of these vapors. If such a location is not available, it may be necessary to partition off a testing area and provide proper ventilation to bring in outside air that is halogen free. When speaking of halogen-free air, it should be understood that the presence of halogen vapors in proportions of ten parts per million may be sufficient to contaminate the air enough to cause a loss of sensitivity in the testing equipment. The use of a fan in one of the windows of the test area sometimes is enough to clear the air for testing.

After a test has been completed and the test piece opened, allowing the detector gas to escape into the room, sufficient time must be allowed to permit the ambient to again become free of halogen vapors. If the waiting period cannot be tolerated, there are two alternatives that may be employed. The test piece can be removed to an outside area before permitting the gas to escape, or a vacuum system can be used to remove the gas before opening the test piece. The use of the vacuum system has been found to be the more satisfactory. Although some gas usually remains in the test piece after vacuum treatment and therefore tends to contaminate the air, the time lost in maintaining clear air is relatively small.

Two general methods have been found useful in the actual testing. The decision on which to use is dependent upon the specific needs. The first method consists of the actual exploration of all possible leak areas and gives both an indication and the location of a leak. The second method is an over-all test that will indicate the presence of a leak but will not give its location.

The first method is undoubtedly the more accurate since the testing probe comes into close proximity to the location of each and every possible leak, thus enabling the probe to pick up the minutest amount of leaking gas before it has time to dissipate, or mix with the surrounding air.

Certain precautions are necessary in this probe exploration. Too rapid a search may miss the very small leak. If this risk is to be avoided, the speed at which the probe is moved must be in proportion to the minimum leak tolerance. In testing equipment for an

---

⁽¹⁾"Electronics Simulates the Sense of Smell," by W. C. White and J. J. Hickey, *Electronics*, Mar. 1948, p. 110.

allowable leak of the order of 0.04 oz per year, the probe travel can be one to two inches per second; but the probe speed should be reduced to ½ inch per second for smaller leaks. Where forced ventilation is required to keep the air free of halogen vapors, it must be stopped during the actual testing or care must be exercised to make certain that drafts do not blow the leaking gas away from the test probe.

An application of this type is now in successful operation in the bushing manufacturing division and is being used (Fig. 3) to test all solder-seal bushings of moderate voltage ratings. The test has been in successful operation for about a year.

The test was installed on a temporary basis and contains nothing but the minimum essentials for adequate testing. It consists of the leak detector, a tank of Freon 12 gas, hand-operated control valves, pressure reducer, pressure gage, rubber hose, and sealing mechanism. The only control of the ambient is a portable fan used to disperse the Freon gas when the bushing is disconnected. During an average day the shutdown time required to properly blow away the escaped Freon gas is approximately seven to ten minutes for each of the bushings tested.

A total of five seals must be explored and the time required to connect, impress the gas, test, and disconnect amounts to three minutes.

No definite figures are available on reductions in testing time in this application since the bushings involved were not regularly tested by the old methods. The design engineers have estimated that an equivalent leak test using earlier methods would require thirty minutes per bushing. On this basis, the new detector has effected at least a fifty percent reduction in testing time.

The second method of testing—the one that will indicate a leak but not locate it—has the advantage that the actual direct labor entailed in the hunting or probe method is limited to those units that do leak. The over-all method requires the entrapping or collecting of leaking gas until a sufficient amount is collected to contaminate the surrounding air. Since Freon gas is slightly heavier than air it lends itself well to this method.

In some circumstances a tray under the test piece will collect the leaking gas, thus making it necessary only to test the air in the tray. In areas where drafts may blow the gas away, it may be necessary to completely enclose the test piece. In either case, sufficient time must be allowed for the gas, from the smallest leak, to collect in sufficient quantities to be detected. Extreme care must be exercised to make certain that all connections to the test piece are tight, not leaking gas to cause a false indication. However, if a leak does occur in the connections, the test can be said to "fail safe" since a leak will be indicated.

Small and Highly Standardized Apparatus

The term Small and Highly Standardized Apparatus is intended to include all of the smaller, high-production-rate type of test pieces such as small cans, glass bushings, lightning arrester housings, and the like.

In testing this type of apparatus emphasis must be placed on high-speed testing with all of its inherent mechanization problems. The actual use of the leak detector is basically the same as for large apparatus testing. It may vary somewhat in that it is often possible to handle the test probe by mechanical means, leaving the hands free to operate controls and to connect and disconnect the test pieces.

The degree of mechanization employed in a testing set-up is dependent upon the production rate, the uniformity of test pieces, and the total time available for hand work by the operator.

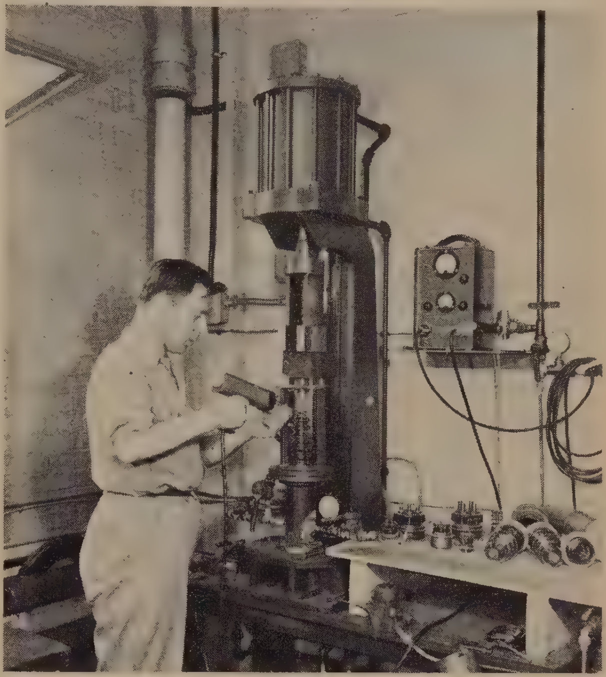


Fig. 4. An application of the leak detector to the testing of apparatus units which are small and highly standardized and therefore make practicable the use of semi-automatic testing auxiliaries

It is not possible to depend on natural dissipation of escaping gas in a high-speed production test, and it therefore becomes necessary to remove the gas in the shortest possible time. The design must therefore include adequate vacuum lines to remove the gas from the test piece, after testing, and proper forced ventilation must be employed to clear the surrounding air. The use of a hood has been found to be the most serviceable for this purpose.

When sufficient incoming air flow is used to clear away leaking gas, steps must be taken to properly direct the air so that it does not remove the gas at the point of the leak before the detector has had time to pick it up and indicate the leak.

At the present time, the glass-bushing division is equipped with two semi-automatic tests (Fig. 4) in which a large part of the actual labor is done mechanically but with the operator actually exploring the bushing leak areas and manually operating all control

(Concluded on following page)

FOR THE PURCHASE OR SALE
OF IRON & STEEL SCRAP
LURIA BROTHERS
& COMPANY, INC.
Have been Serving Industry
SINCE 1889

Main Office
LINCOLN-LIBERTY BLDG.
Philadelphia 7,
Pennsylvania

Yards
LEBANON, PA.
READING, PA.
DETROIT (ECORSE), MICH.• MODENA, PA.
PITTSBURGH, PA.

Branch Offices
BIRMINGHAM, ALA. Empire Bldg.
BOSTON, MASS. Statler Bldg.
BUFFALO, N.Y. Genesee Bldg.
CHICAGO, ILL. 100 W. Monroe St.
CLEVELAND, O. 1022 Midland Bldg.
DETROIT, MICH. 2011 Book Bldg.
HOUSTON, TEXAS Cotton Exchange
LEBANON, PA. Luria Bldg.
NEW YORK, N.Y. Woolworth Bldg.
PITTSBURGH, PA. Oliver Bldg.
PUEBLO, COLO. Colorado Bldg.
READING, PA. Luria Bldg.
ST. LOUIS, MO. 2110 Railway Exchange Bldg.
SAN FRANCISCO, CAL. Pacific Gas & Elec. Co., Bldg.

ASSOCIATED
ELECTRICAL
INDUSTRIES
• LIMITED •

British Thomson-Houston Co., Ltd.
Edison Swan Electric Co., Ltd.
(*Incorporating Harcourts Limited*)
Ferguson Pailin Limited
Hotpoint Electric Appliance Co., Ltd.
(*Incorporating International Refrigerator Co., Ltd. and Premier Electric Heaters Ltd.*)
Metropolitan-Vickers
Electrical Co., Ltd.
Metropolitan-Vickers-GRS. Ltd.
Newton Victor Ltd.
• •
Agents and Licensees of the
GENERAL ELECTRIC Co., U.S.A.
for the United Kingdom.
A3951

HOW TO TEST FOR LEAKS

(Continued from preceding page)

valves. A single operator can easily test at the rate of forty bushings per hour. A later design of set-up will permit testing at the rate of one bushing every eight seconds. The work done by the operator will be limited to the loading and unloading of the test fixtures and to the operation of push-button controls. All sealing of the test piece in the testing chamber will be automatic and all controls will be sequence-operated through the pushing of a single push button.

The set-up will be limited to large production outputs where identical sizes and shapes will permit the use of a close fitting cover. This will allow the use of an over-all test with a minimum of waiting for the collection of the leaking gas. After a leak is indicated, the actual location will be made by the usual hand hunting method.

Liquid-filled Apparatus

The use of the leak detector is not limited to apparatus into which a detector gas can be impressed. In a liquid-filled sealed unit the same leak-testing techniques can be employed provided one of the halogen compounds can be added to the liquid at the time of filling without detriment to the liquid. The compound used must be one that will quickly vaporize. In some types of electrical and thermal apparatus, such as liquid-filled indicating thermometers and liquid-cooled equipment, the liquid used may itself contain a halogen compound and therefore will not require any additives.

CONCLUSIONS

The application of the leak detector to production testing can be expected to result in a substantial savings in both testing costs and testing time.

Actual increases in production testing output of the order of one thousand percent, and savings in the cost of testing of fifty percent, are by no means unusual.

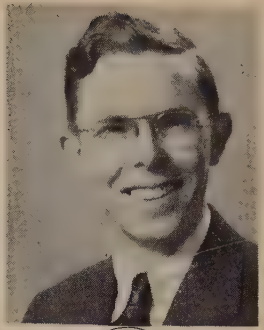
Consistent results in improved quality have been indicated and these supply the design engineer with the data so necessary to lower costs and improve products. In line with this improved quality has been the continuous indication of reduction in complaints.

SEXTON CAN COMPANY
Incorporated
Everett Massachusetts
Manufacturers of
Ash Barrels
Kitchen Waste Cans
Underground Garbage Receivers
CAPACITOR CASES
both Fabricated and Deep Drawn
FIVE GALLON
Open and Closed Top Shipping Containers
METAL STAMPINGS
SPECIAL SHEET METAL WORK

SELF-BALANCING RESISTANCE BRIDGE

An electronic means of obtaining bridge balance eliminates tedious and time-consuming operations and offers other advantages for rapid production testing. Construction principles and factory application

By H. F. RONDEAU
Locomotive and Car Equipment Divisions Laboratory
General Electric Company



H. F. Rondeau

HOW can accurate resistance measurements of electrical components be made on a production basis in a minimum of time? It was this question which prompted the development of a resistance-measuring device which would be an improvement over the conventional-type bridges usually used for production testing.

Conventional bridges, such as the Wheatstone and Kelvin, are the acceptable instruments used in factory testing. These require a reflecting- or pointer-type galvanometer, which is sensitive to vibration and tedious to operate.

Anyone acquainted with these bridges appreciates the time required to obtain an accurate bridge balance. This point is given further emphasis if a conventional bridge is used to set resistance taps on an adjustable resistor. The process resolves into one of trial and error in which much time is lost.

CONSTRUCTION OF SELF-BALANCING BRIDGE

To overcome many of these disadvantages and still retain accuracy in resistance measurements, it was considered advisable to adopt an electronic method of obtaining bridge balance. This was accomplished by obtaining a servo-system which automatically balances the bridge for any test resistance within the range of the instrument.

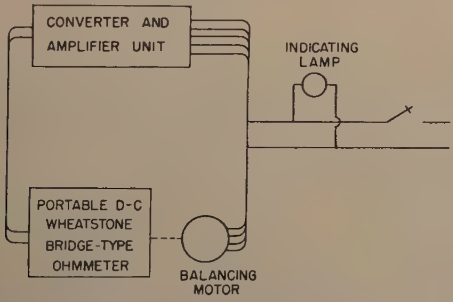

CONVERTER AND AMPLIFIER UNIT
INDICATING LAMP
110V 60∿
PORTABLE D-C WHEATSTONE BRIDGE-TYPE OHMMETER
BALANCING MOTOR

Fig. 1. Block diagram of self-balancing bridge components

The resulting self-balancing bridge, shown in FIG. 1, operates on the common 115-volt 60-cycle lighting circuit, and consists of three major components, an ohmmeter of the Wheatstone bridge type and an electronic converter feeding a balancing motor. Slight wiring changes were made in the commercial ohmmeter so that it could be operated manually or automatically.

The conventional Wheatstone bridge diagram, shown in FIG. 2, includes a single-pole double-throw switch which can be placed in either the "automatic" or "manual" position. With the switch in the former position, the galvanometer is bypassed and any out-of-balance voltage which would normally cause the galvanometer to deflect is sensed by the converter. This vibrator-type unit, operating on 60-cycle power, sends pulses of the unbalance voltage through a transformer. When the d-c input voltage polarity changes, a 180-deg phase shift is effected at the converter output. An electronic voltage and power amplifier steps up the converter microvolt a-c output to several volts. A reversible, two-phase 60-cycle induction motor receives this voltage and drives the bridge slide-wire contact *A* in such a direction as to make the out-of-balance voltage a minimum. This action is more clearly understood by considering what takes place in the motor. One winding of the motor is continuously excited by line voltage; the other winding is excited by the power amplifier. The phase relationship of the currents in these windings determines the direction of the motor rotation.

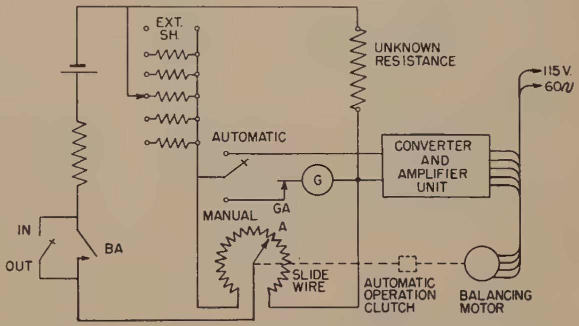


Fig. 2. Schematic connection diagram of self-balancing bridge

By referring again to FIG. 2, it will be noticed that an IN-OUT switch has been shunted around the battery switch. When this is closed or in the IN position for automatic operation, it is unnecessary to hold down the *BA* switch as in manual operation.

The ohmmeter resistance dial and balancing slide wire are mechanically coupled to the balancing motor by a friction clutch which is engaged during automatic

---

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

operation. The clutch is geared to the motor pinion in such a manner as to realize a sizeable speed reduction.

The automatic balancing time can be appreciated readily when it is realized that the time required for the balancing scale to be driven from the zero to the infinite resistance graduation is about 24 sec. Not more than one or two seconds should be required to obtain a reading, if the resistances being measured vary only slightly.

Since the ohmmeter was originally designed for manual operation, this feature was retained. Moreover, it is a simple matter to change from automatic to manual operation by (a) disengaging the slide-wire clutch, (b) switching the short-circuiting switch to the OUT position, and (c) placing the galvanometer in the circuit by throwing the single-pole double-throw switch to manual. This is convenient for two reasons: it is desirable to make an occasional manual check on a reading obtained automatically to insure that the self-balancing equipment is functioning properly; and it is also valuable in demonstrating that, within practical limits, the resistance measurements obtained automatically are more accurate than those obtained by a manual balance.

An assembled view of the self-balancing resistance bridge is shown in FIG. 3. This is similar to the self-balancing Kelvin double bridge developed for determining the temperatures of traction motors by resistance measurements.(1)

APPLICATION IN THE FACTORY

There are many production tests requiring an accuracy of ±0.5 percent to ±5 percent or greater in which the self-balancing bridge will indicate a measurement in a small fraction of the time ordinarily required to make a similar measurement by conventional methods.

This bridge was found to be useful in setting the several taps on an adjustable resistor. After the bridge leads are clipped on the resistor taps, the operator can observe a continuous resistance reading on the bridge resistance-dial as he moves the adjustable tap to the desired position for permanent setting. Without this self-balancing feature, it might be necessary to relocate each tap several times before obtaining a resistance value within the tolerable limits.

Another application for this bridge is measuring the resistance of contactor, regulator, breaker, and other types of relay coils which vary from 25 to 10,000 ohms and have a tolerance of about ±5 percent.

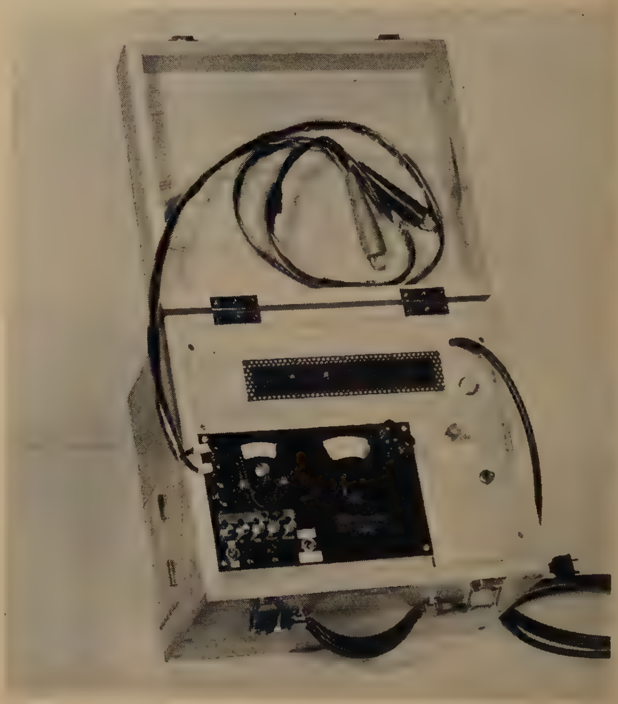


Fig. 3. Self-balancing bridge unit shown with cover of case open

Wherever there are production tests which require the measurement of resistances ranging from 0.01 ohm to 30,000 ohms or higher with an accuracy of about 1 percent, this self-balancing bridge is found to be suitable. Also, it is possible to vary the range and accuracy by choosing a suitable ohmmeter.

CONCLUSION

The self-balancing resistance bridge finds its principal application where it is necessary to make accurate, repetitious resistance measurements. It is low in cost, simple in construction, sturdy, easy to operate, resistant to vibration, time-saving, and portable. The reliability of its indications has been tested at various locations throughout its range by comparing the manually obtained reading with the self-balanced indication. In nearly all of the tests, the indications were within approximately 0.2 percent agreement.

The characteristics of this instrument, mentioned previously, make possible its use in many new applications. Further attention should be given to the benefits that may be derived from the application of the self-balancing principle to other types of bridge circuits and instruments where balancing is a time-consuming operation.

---

(1) This instrument is described in the October 1948 issue of the GENERAL ELECTRIC REVIEW in an article on "Determining Temperatures of Traction Motors" by J. W. Teker and F. H. Catlin.

RETURN YOUR 1948 COPIES FOR BINDING

We will prepare them for you in our attractive and durable, standard gold-stamped, black half-morocco leather binding, with cloth sides.

The price is only $6.00 a set (extra postage for return delivery outside the U.S.A., $1.00). We can still replace any missing issues (except June★) and the annual index for 1948 at $1.00 each.

Also, we can supply volumes already bound for the years 1941★ thru 1948 in the above binding at $10.00 an annual volume (plus $1.00 for delivery outside U.S.A.). Prices of others on request.

GENERAL ELECTRIC REVIEW
SCHENECTADY, N. Y., U. S. A.

★Correction to ad which appeared in Sept. issue.

CHOOSE YOUR STOKER WITH CONFIDENCE

from the experience of thousands . . .

Iore than ever, with today's coal prices, getting the right toker pays big dividends. And the choice of the right stoker or your steam load, boiler design and available fuel is greatly mplified when you turn to Combustion for the answer. Vhy? Because over 20,000 C-E stoker installations (above esidence size) make available to you an accumulated expeience unmatched by any other stoker manufacturer.

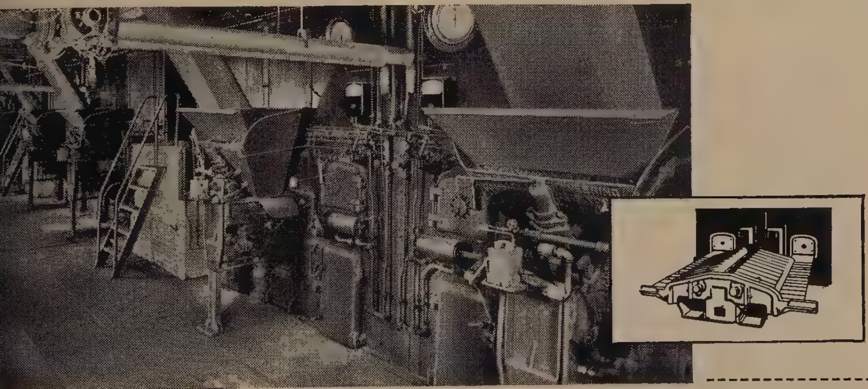
Coupled to this unparalleled experience is a *complete* line f stokers which includes *every* basic type, thus eliminating he possibility of any bias in our recommendation to you nd assuring you of a completely satisfactory choice.

Out of these thousands of installations, three stoker designs stand out as most suitable for today's needs . . . the Skelly and Type E (both single-retort underfeed types) and the Spreader Stoker. In fact, these three types have been applied in ninety out of every hundred C-E stoker installations made in recent years. Yet, if your requirements fall within the 10 per cent group, Combustion offers you other designs which round out the most complete line of stokers available anywhere.

Check your needs against these three . . . then have one of our engineers verify your choice.

B-225B

SKELLY STOKER UNIT — Approximate Application Range — 20 to 200 boiler hp. A compact, self-contained underfeed unit available in designs for burning either anthracite or bituminous coal. An alternate arrangement of fixed and moving grate bars assures lateral distribution of fuel and maintains a clean porous fire. Cantilever dump grates of non-avalanching type simplify ash removal. An integral forced-draft fan, with vortex inlet control, permits positive regulation of air-coal ratio. Sixteen rates of coal feed through variable-speed transmission. Automatic control is standard equipment. Timken bearing equipped. Alemite lubrication throughout.



TYPE E STOKER — Approximate Application Range — 150 to 600 boiler hp. A single-retort, underfeed stoker designed to burn a wide variety of bituminous coals, particularly those having caking and coking characteristics. The Type E has ram type feed supplemented by a reciprocating sliding bottom. Its grate surface consists of hollow, air-cooled grate bars arranged in an alternately fixed and moving relationship to condition the fuel bed and assure its steady movement to the dump trays which are of the cantilever type. Air supply is under zoned control with provision for introduction of air over the fire. Type E Stokers are available with steam, electric or hydraulic drive.

SPREADER STOKER — Approximate Application Range — 150 boiler hp. up to units producing 200,000 lb of steam per hr, or more. The C-E Spreader Stoker is available in both dumping grate and continuous discharge types and is designed to burn a wide variety of coals. A series of rotating spreader blades feeds coal into the furnace in criss-crossing streams which assure uniform distribution. Fines are burned in suspension and the rest of the coal is burned on the grate. Grate surface is zoned for regulating air admission and to facilitate cleaning. Rate of fuel feed and air supply may be regulated over a wide range and are readily adaptable to automatic control.

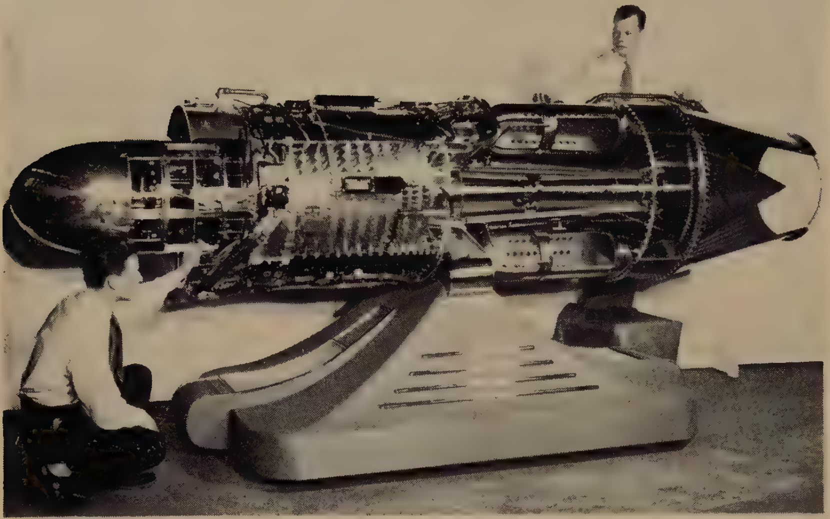
Combustion Engineering—Superheater, Inc. C-E

A Merger of COMBUSTION ENGINEERING COMPANY, INC. and THE SUPERHEATER COMPANY

200 Madison Avenue, New York 16, N. Y.

HIGH LIGHTS AND SIDE LIGHTS

Interior View of the Turbojet



By means of this cutaway jet engine, internal operation of the J-47 turbojet was demonstrated publicly for the first time at Cleveland, during the National Air Races. The engine is equipped with an aircraft-type throttle with which visitors can start the engine to see it perform the motions of an operating unit

TELEMETERING GYROS

Giannini telemetering units include rate gyros calibrated for rotational measurements of 10° to 1000° per second, and position gyros with one or two axis electrical sensory elements. All gyros operate from 24 volts dc.

Recently expanded manufacturing facilities afford firm delivery of 1949 improved instrument and powerplant equipment.

Latest Technical Catalogs on Request

G. M. Giannini & Co. Inc.

285 W. Colorado, Pasadena 1, California
697 Morris Turnpike, Springfield, N. J.

Synchrotron to Be Used for Cancer Research

A 70,000,000-volt synchrotron has been purchased by the University of California Medical School for use in the fight against cancer.

First machine of its type for the study of high-frequency radiation in the treatment of cancer, the new x-ray generator is expected to be ready early in 1951. The Atomic Energy Commission will provide funds for the instrument and its operation.

Developed originally for atomic research, the synchrotron is believed to have great possibilities in medical research and therapy, enabling physicians to explore the therapeutic effectiveness of x rays with energies far beyond those provided by conventional x-ray generators, which have already accomplished excellent results in the treatment of cancer.

Distribution of the x-ray energy absorbed in the patient's body changes markedly with large changes in voltage of the x rays used. Studies of doses at various depths indicate that for each voltage there is a particular depth at which the rays have their maximum effect. Hence, the scope of a research program exploring the therapeutic usefulness of these higher-energy radiations will be greatly extended by the use of a machine that can generate such radiation over the widest possible range of energy levels.

In the operation of the synchrotron, electrons originating from a heated filament are whirled around in a doughnut-shaped vacuum tube. This is placed between the poles of an electromagnet, which speeds the electrons by magnetic forces up to an energy of about two MEV, where they are moving at more than 183,000 miles per second, or about 97 percent of the speed of light.

Inside the doughnut is a metallic gap, connected to what is essentially a short-wave radio transmitter. The gap becomes energized as the electron speed approaches that of light, beyond which the electrons cannot go. Each time the electrons pass the gap, they get an additional supply of energy. When they are moving at practically the speed of light, this causes an increase in their mass rather than in speed.

While the electrons are accelerated by radio oscillations, the field of the electromagnet continues to hold them in their essentially circular orbits. When the desired energy is reached, the oscillations are cut off. The electrons spiral inwards, hitting the tungsten target and generating a beam of x rays which comes out of the tube in a straight line.

Precision Power-supply Equipment

The National Bureau of Standards has received what is believed to be the most accurate wide-range electric power controller yet made by man.

Electric power fed through the new wide-range power-supply equipment is kept from varying more than 0.005 percent. The instrument will be used by the Bureau of Standards in making electrical measurements requiring a virtually unwavering power supply. Since voltage on an ordinary power supply may vary by as much as ten percent, it consequently cannot be used in delicate measurements.

The new equipment features a continuously variable voltage output from 500 to 50,000 volts, with a maximum current output of one milliampere. The high voltage is attained through the use of a radio-frequency oscillator, power amplifier, RF transformer, and a ladder-type voltage-tripler circuit. Use of the RF source, about 40 kc, makes possible reduction of the output ripple to a low value by a simple filtering means. This minimizes the equipment's weight (350 lb) and size (84 × 23 × 20 in.).

The wide-range power supply has been designed with exceptional stability as to output voltage, ripple, and load regulation. Output power, supplied through a 15-ft x-ray cable, is not affected by variations in line voltage or frequency. Ful mpensation is made for ambient-tem- rature changes, and precision regulation attained through the use of two regulat- g loops in cascade.

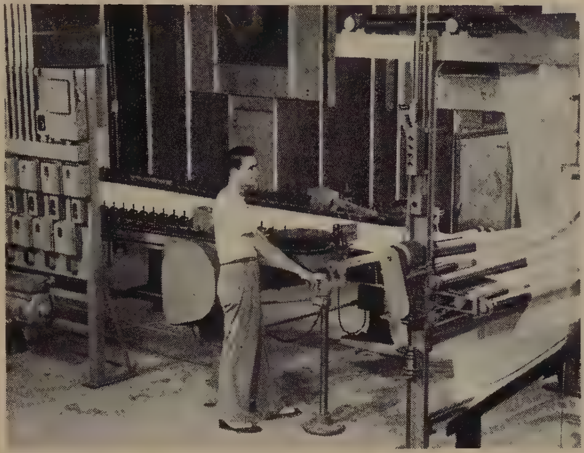
Power to be monitored is fed into con- ctions at the base of the apparatus, run rough the 32-tube electronic controlling rcuit, and brought out through cables at e unit's top.

Individual card drives, in a Georgia cotton mill, help to boost production, eliminate the expense of maintaining belts, pulleys, etc. One example shown in "Textiles Unlimited"

More Power to America's Textile Mills

What is perhaps the first comprehensive sual program devoted exclusively to a view of major modernization trends in e textile industry has been announced in e new Textile Mill Modernization Pro- am, thirteenth in the More Power to merica series. The program is designed show how textile mills can increase oductivity, improve product quality, nd reduce costs through increased use of odern equipment and processes.

A 16-mm, sound-color motion picture, Textiles Unlimited," and a 104-page, mitechnical manual (described in Trade iterature, page 55) dealing with moderni- ation trends in the industry are to be own throughout the country to inter- sted textile-mill executives, engineers, and perintendents; textile-machinery manu- cturers; and to personnel and associa- ons allied with the industry.

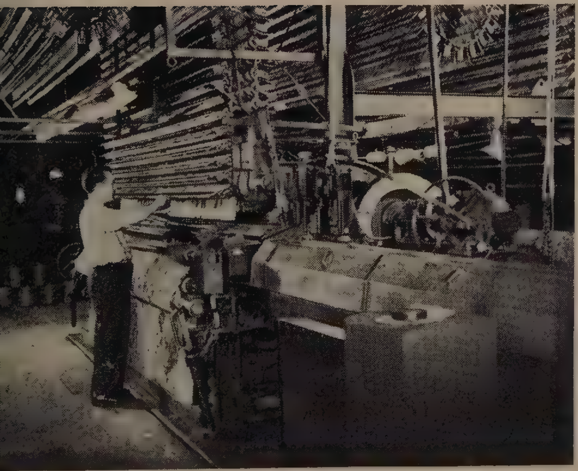


Electronic weft-straightening in a Southern finishing plant

ew dye jig with precise elec- rical control, in operation in a nishing plant

"Textiles Unlimited" is a product of more than two years' research and reporting, which took cameramen and engineers through textile mills and laboratories from Maine to Alabama.

The film shows for the first time on the screen many new equipments and processes under development in laboratories, pilot plants, and mills throughout the East. In an interesting series of sequences, it illustrates the important role electric equipment is playing in the industry's program to produce highest quality textiles at the lowest possible unit cost.



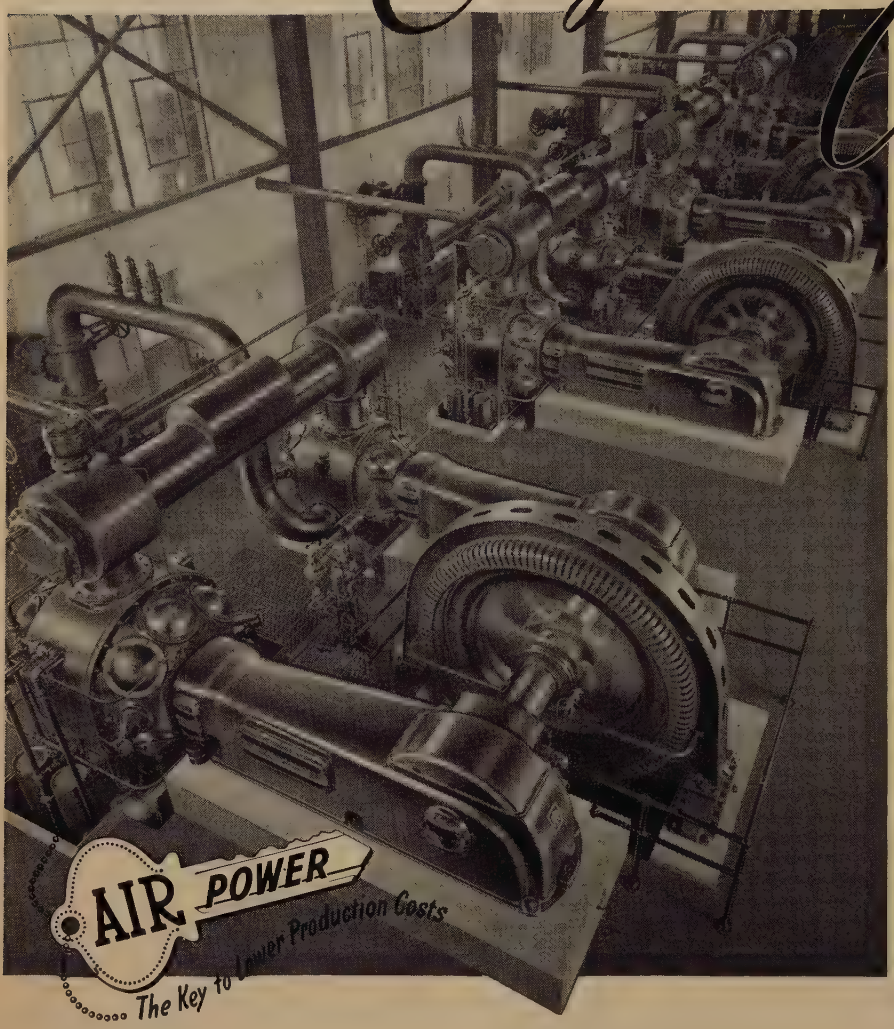
Axminster loom powered by adjustable-speed drive

Rapid Heat-treating

A tempering process which heats a metal surface from room temperature to a bright red 1600 Fahrenheit and cools it again to room temperature, all within less than five seconds, has been developed for the tempering of small metal parts.

The process uses an electromagnet, which holds the part to be tempered within the field of a powerful electronic heater. As soon as the part has been heated to the proper temperature, an automatic timing switch shuts off the electronic heater. At the same instant, the current is removed from the electromagnet and the part drops into a cooling bath of oil.

The process is being used to harden the surfaces of parts which must be able to withstand heavy impacts.



BACK OF *Every* INGERSOLL-RAND *Compresso*

ARE THESE

*Sup*IR*value*

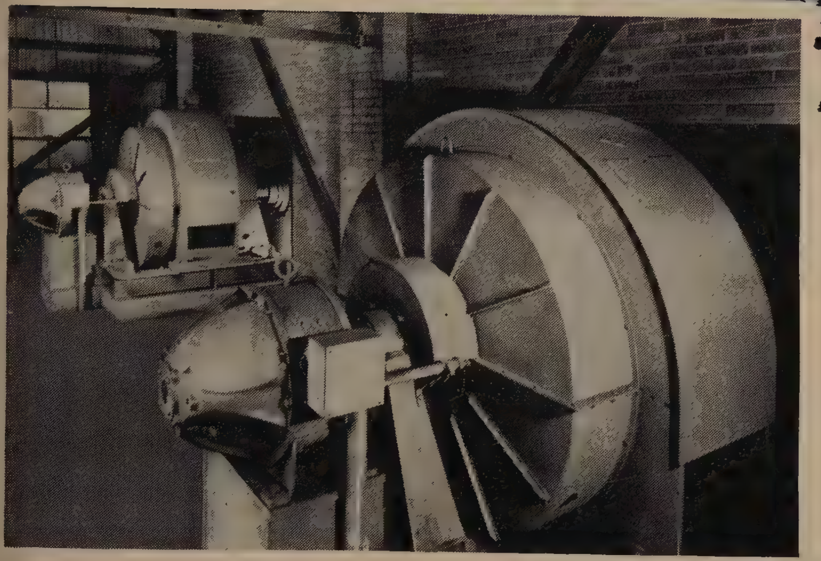
- **Tradition**...a 77-year old company that grew from the *two of the earliest* compressor builders in America.
- **Experience and Know-how** to build compressors for *any* pressure, *any* gas, *any* size, *any* service.
- **Facilities** *second to none...* for design, research, metallurgy, and manufacture.
- **Range of sizes** . . . with *standardized* frames, running gears and interchangeable cylinders ...plus *special* cylinders, valves and coolers for special applications.
- **Flexibility of Drive** . . . a *choice* of compressors powered by electric motor, oil, gas, or steam.
- **Record of Performance** ...thousands of compressors successfully operating in *every* branch of industry.
- **Design Features** that give you the best in efficiency, durability, dependability, easy operation, and low maintenance.
- **Trained Personnel** ...men who *know* Air Power...who build, sell, and service air drills and tools as well as compressors.
- **Progressive Policy**...*continuous* pioneering and development of both new and old products.
- **Service** ...with offices in principal cities *all over the world.*

This 2800-horsepower installation of Ingersoll-Rand *Class PRE Compressors* generates the Air Power for one of America's outstanding metal mines. It is typical of thousands of similar heavy-duty compressors that are so essential in practically every industry.

Whether they supply Air Power for Air Tools in factory, mine, or construction work, or compress hazardous gases at extremely high pressure in a costly process, the purchaser must rely upon the experience and judgment of the manufacturer for a dependable compressor that meets his specific requirements. To make sure you get the best, select an Ingersoll-Rand Compressor...backed by *Sup*IR*values*

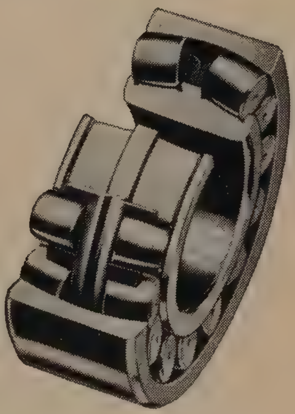
Ingersoll-Rand
11 BROADWAY, NEW YORK 4, N. Y. 267-1

COMPRESSORS · ROCK DRILLS · AIR TOOLS · BLOWERS · PUMPS · ENGINES · HOISTS · VACUUM EQUIPMEN



Electric Machinery Mfg. Company's synchronous motors directly connected to Pennsylvania Crusher Company hammermills at the Jones & Laughlin Steel Company plant in Aliquippa, Pa. The motors are 500 hp, 750 rpm, 440 volt.

SYNCHRONOUS MOTORS THAT DRIVE RUGGED HAMMERMILLS USE LONG-LIFE SKF BEARINGS



Synchronous motors made by the Electric Machinery Mfg. Company, of Minneapolis, Minn., are always called upon to perform at top efficiency. This is especially true in driving heavy-duty hammermills, where the motors must operate on a long-run, low-maintenance basis.

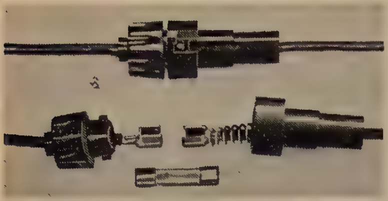
In the hammermill installation at Jones and Laughlin, for example, each of the driving motors is equipped with two SKF Spherical Roller Bearings on the rotor shaft. These bearings help to insure satisfactory motor performance through the elimination of frequent bearing adjustment and lubrication. Because they are fully self-aligning, the capacity of the bearings is not affected by shaft distortion or deflection resulting from overloads.

Other manufacturers of electrical equipment—like the Electric Machinery Mfg. Company—are looking to SKF for the best solutions to their bearing problems. Let SKF engineers help you to put "The Right Bearing in the Right Place."

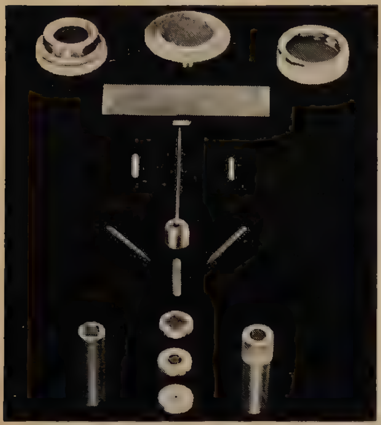
Write to: SKF Industries, Inc., Philadelphia 32, Pa 6642

Electrical Equipment Bearings engineered by **SKF**

NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM



Fuse Holder



Nuclear Detecting Devices

Nuclear Detecting Devices

A group of new devices designed to answer a requirement of the atomic era—the standardization of instruments used to detect or measure nuclear forces. Each of the units shown—from pin points to various measured areas of radiation surface—has been specifically designed to furnish alpha, beta, or gamma particles at an accurately known rate. Usually radium is the source but other long-lived radioactive materials may also be used. All are products whose basic processes for incorporating radioactive sources in foil make practical standardized area-sources of radiation.—*United States Radium Corp., 535 Pearl St., New York 7, N. Y.*

Harmonic Generator

A new educational device, called a harmonic generator, for the demonstration of wave shapes and properties of electrical circuits. The portable equipment consists of six voltage-generating units mounted on a single shaft driven by a synchronous motor. The outputs obtained are a fundamental voltage and five harmonic voltages having frequencies 2, 3, 4, 5, and 7 times that of the fundamental voltage. The impulses are fed into an oscilloscope which translates into images on a screen the impulses of the waves generated. With this equipment virtually any wave shape needed in a given engineering problem can be produced, including square waves, saw-tooth waves, Lissajous figures, Doppler effect, wave shapes across electrical impedances, resonances of circuit components, and many others.—*General Electric Co., Special Products Division, Schenectady 5, N. Y.*

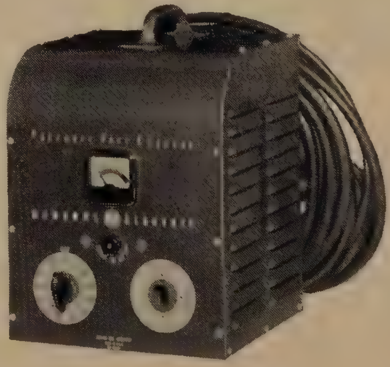
Fuse Holder

Utilizing the principle of a tube-socket contact of proper diameter, a new fuse holder has been developed for in-the-line service in electrical and electronic equipment. Positive contact is assured by attaching the wire lead to the socket-type contact by a solderless crimp connection, thus making these two parts an integral unit.

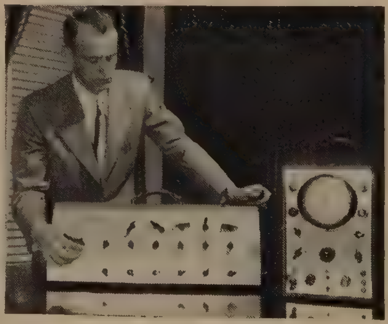
After three insertions of a 0.253-in. diam pin there is a maximum voltage drop of five millivolts at 20 amp when measured with a 0.247-in. silver-plated copper pin. Maximum strength is obtained in the design of the key of the molded cap, which locks securely and unlocks easily when desired.—*Hugh H. Eby, Inc., 4716 Stenton Ave., Philadelphia, Pa.*

Auto Battery Charger

A new, small, portable, fast selenium-rectifier charger for automobile batteries designed for use in garages, service stations, and automobile repair shops, and for emergency home-service use. This charger draws 12.5 amp and has a maximum output of 80 amp which can be maintained for long periods. A circuit breaker and fuse offer double protection against overloading the charger or connecting the battery backwards. An ammeter on the front of the metal case indicates the charging rate. The charger also is equipped with a timer for setting safe recharge periods and a central switch which regulates the charging rate to overcome varying battery conditions and varying a-c line voltage.—*General Electric Co., Lighting and Rectifier Divisions, West Lynn, Mass.*



Auto Battery Charger



Harmonic Generator

Wristlock Disconnect

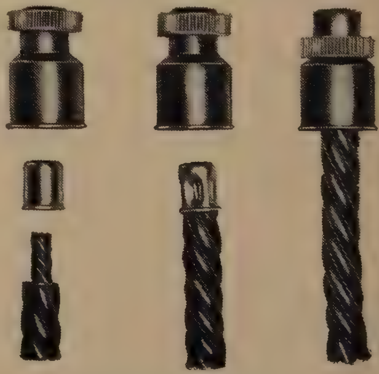
A new Sta-Kon disconnect, named the Wristlock, consists of two identical halves. Thus, it is not necessary to mate unlike parts; halves can be simply meshed and locked securely together by hand. It is so designed that it will not let go in line of pull, and cannot swivel out of connection. It makes a positive electrical connection, and has a brazed barrel giving extra strength, and also an excellent insulation grip. The disconnect was designed particularly for use with relays, signal or elevator equipment, many types of fractional horsepower motors, etc.—*Thomas & Betts Co., Inc., Elizabeth, N. J.*

Pump Piston

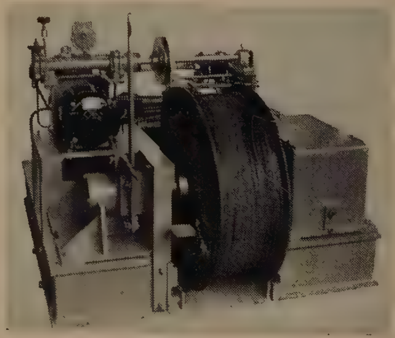
A new pump piston machined from nylon for use in industrial filters. These pistons have been found to be resistant to abrasion from lamp black, and other abrasive powders used as filter aids. In addition, they also have the advantage of toughness and strength to prolong product life; chemical resistance to dilute acids, etc.; and quiet operation without lubrication.—*Polymer Corp., Reading, Pa.*

Insulated Splice Caps

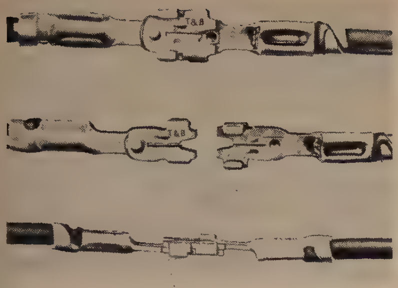
Splice caps with insulators now available in new large size which will accommodate five No. 14 or three No. 12 to two No. 6. The splice cap is installed quickly and securely by means of a crimping tool having four uniformly converging plungers which draw the cap and inserted wires into a solid permanent mass. The installed cap is insulated rapidly and securely by pushing a molded insulator over splice cap and turning up the security ring to lock insulator firmly in place.—*Buchanan Electrical Products Corp., 1290 Central Ave., Hillside, N. J.*



Insulated Splice Caps



Spooling Unit



Wristlock Disconnect

Die Checker

Die Checker

The Pant-O-Scriber die checker provides a fast, accurate, and inexpensive visual method of gaging contour profiles, flash, and striking surfaces for forging dies and punches. Some of the features this checker offers are: fast semiautomatic operation; permanent inspection record of die sets; periodic quality-control check for die wear; checking of master die set, or wear, in relation to master chart, as well as checking of shrinkage between die and forged part; and use of skilled or highly trained operators not required. The equipment has been designed and built to make it possible for operators to check dies which form anything from very small jet engine blades to those 3 ft in length and other comparable proportions.—*Engineers Specialties Division, 980 Ellicott St., Buffalo 8, N. Y.*

Spooling Unit

A new high-speed spooling unit designed for use where tension control and constant lineal speed are important. It can be adapted to many applications that require take-up or winding equipment, such as web processing, strip stock takeups, payoffs, and rewinders. It can be supplied with or without the level-wind traversing mechanism as required. Typical installations would be in continuous annealing, electroplating, galvanizing, cleaning, and tinning lines. The particular unit illustrated is so designed that it operates directly from the finishing block of a wire-drawing machine, finishing at 1500 fpm wire speed. As much as 500 lb of wire is carried onto the spool with constant tension on the wire. Provision is made to adjust the tension between 10 and 20 lb as required.—*Black Industries, 1400 East 22nd St., Cleveland 17, Ohio.*

INSTANTANEOUS

recordings from D.C. to 100 cps!

Accurate recordings of voltages, pressures, strains, vibrations and countless other phenomena.

Permanent ink on paper recordings by Brush Oscillographs make their use almost unlimited.

Either A. C. or D. C. signals can be measured. Whenever desired, recordings may be stopped for notations on chart-paper.

- Investigate Brush measuring devices before you buy . . . they offer more for your money . . Why not have a Brush field engineer call? At no obligation, of course. Just call or write . . today . . you will find it worth a few seconds' time!

THE Brush DEVELOPMENT CO.

3405 Perkins Avenue · Cleveland 14, Ohio, U. S. A.

MAGNETIC RECORDING DIV. · ACOUSTIC PRODUCTS DIV.

INDUSTRIAL INSTRUMENTS DIV. · CRYSTAL DIVISION

Canadian Representatives: A. C. Wickman, (Canada) Ltd., P. O. Box 9, Station N, Toronto 14

NEW! small

d-c capacitors for use in ambient temperatures up to 125°C

Permafil capacitors are similar in appearance and construction to other General Electric paper-dielectric capacitors. Permafil, the impregnant, has excellent insulating properties at high temperatures.

General Electric announces a new line of Permafil d-c paper-dielectric capacitors designed especially for operation in high ambient temperatures. They require no derating for temperatures up to 100° C and can be used up to 125° C.

Hermetically sealed in metallic containers, these new units are available in case styles 61, 63, 65 and 70, as covered by Joint Army-Navy Specifications JAN-25-C, in ratings of 0.10 to 4.0 muf 600-, 1000- and 1500-volts. Permanently sealed silicone bushings are provided on all types.

Permafil capacitors were developed to provide suitable components for the many new applications involving continual operation at ambient temperatures above 85°C—another example of capacitors "designed for the job" by G-E engineers. For further information on these or on capacitors for other applications, write *Capacitor Sales Division, General Electric Company, Pittsfield, Mass.*

GENERAL ELECTRIC

407-162

Specialty Capacitors FOR

- Motors
- Luminous-tube transformers
- Fluorescent lamp ballasts
- Industrial control
- Radio filters
- Radar
- Electronic equipment
- Communication systems
- Capacitor discharge welding
- Flash photography
- Stroboscopic equipment
- Television
- Dust precipitators
- Radio interference suppression
- Impulse generators

AND MANY OTHER APPLICATIONS

TRADE LITERATURE

lloys—The known applications and uses r low-temperature-melting Cerro alloys e listed following a brief history and a sume of the characteristics and physical operties of these alloys. Four pages. illetin J4-6-49.—*Cerro de Pasco Copper rp., 40 Wall St., New York 5, N. Y.*

onnectors—The fourth edition "Labora- ry and Switchboard Connector Series" scribes 12 different standard fittings, nging from one to four contacts, all rated amp for switchboard plug requirements all types of laboratory testing equipment d experimental stations. Application otographs, dimensional sketches, and sembly photographs are included. Eight ges. Bulletin LS4-1248.—*Cannon Electric evelopment Co., Cat. Dept. 3209 Humboldt ., Los Angeles 31, Calif.*

luorescent Lighting—Mainly pictorial content, this publication shows installa- on photographs of Val-Lite fluorescent ghting fixtures which feature merchandis- g displays, point-of-purchase advertising, nd general commercial illumination. Con- truction features are listed, as well as pecifications. Eight pages. Form No. 9-101.—*Kent-Moore Organization, Inc., ighting Div., General Motors Bldg., Detroit , Mich.*

eat-treating and Pickling—Presents omprehensive and up-to-date information n heat-treating and pickling methods for tainless steels. Recommended procedures, ased on practical experience, are given in detail for the chromium-nickel, ferritic chromium, and martensitic chromium types of stainless steel. Extensive use of charts and graphs. Thirty-six pages.—*Armco Steel Corp., Middletown, Ohio.*

Insulating Film—This folder describes how Scotch-Weld electrical insulating film No. 70 speeds production and improves the life and performance of electrical coils. Four pages.—*Minnesota Mining and Manufacturing Co., 900 Fauquier St., St. Paul 6, Minn.*

Lubricant—The principle of Molykote, Type Z, an extreme pressure lubricant is explained in detail and many of its purposes are defined. Four pages. Bulletin No. 52.—*The Alpha Corp., Greenwich, Conn.*

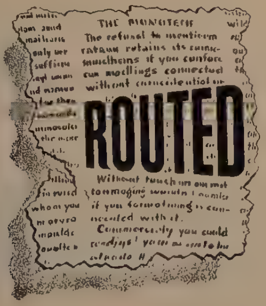
Metal Screen—In this folder are described the special features and uses of Lektromesh metal screen which is formed by the electro-deposition of pure copper, pure nickel, or a combination of the two metals. Four pages.—*C. O. Jelliff Mfg. Corp., Southport, Conn.*

Outdoor Lighting—Many helpful suggestions are given for proper lighting of industrial plants. Adequate lighting of roadways, loading platforms, parking areas, and property lines can easily be obtained with the luminaires and floodlights that are described. Sixteen pages. GEA-3640B.—*Apparatus Dept., General Electric Co., Schenectady 5, N. Y.*

Power: Textile Mills—An illustrated manual titled "How Textile Mills Are Modernizing" is a report to the industry on general trends and specific new methods and equipment. Prepared in co-operation with textile machinery manufacturers, textile research organizations, trade journals, and textile mills, it covers in detail the major trends which include: comprehensive mill conditioning; modern materials handling; applying power at the point of use; higher average speeds; finer quality control; continuous processing; new electric tools, and new processing methods. Price $1,25. Ninety-four pages. GEA-4998.—*General Electric Co., Apparatus Department, Schenectady 5, N. Y.*

Radio and Electronic Supplies—This catalog contains engineering data and descriptions of many new products for use in the radio and electronic field. It includes jacks, plugs, and switches for low-power applications. Schematic circuits, detailed line drawings, and prices are given. Twelve pages. Catalog No. S49.—*Switchcraft, Inc., 1328-30 N. Halsted St., Chicago 22, Ill.*

Volt-ammeter—A bulletin devoted to a pictorial explanation of the Amprobe, a pocket-sized split-core volt-ammeter designed for the maintenance man, engineer, electrician, motor repair, and service shop. Four pages. Catalog No. 109.—*Pyramid Instrument Co., 49 Howard St., New York 13, N. Y.*



ROUTED COPIES

When picking up a magazine, nothing is more disturbing than to find that an important article has been clipped out.

Because of the permanently useful information in the REVIEW, many of its articles are clipped out so that material can be conveniently available for reference purposes.

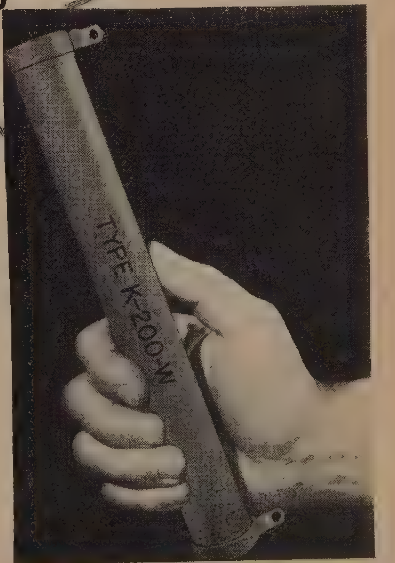
In order that you may have your own copy of the REVIEW, we suggest that you subscribe, now.

GENERAL ELECTRIC
REVIEW
SCHENECTADY 5, NEW YORK

SUBSCRIPTION RATES: One Year $4.00; Three $8.00
Extra postage (1 or 3 yr.)—Canada $1.00; Foreign $2.00

GREENOHM Power Resistors

5 to 200 watts, standard. Fixed or adjustable. Also with taps, all types of terminals and mountings, on special order.



★ **Yes sir, POWER! These Clarostat power resistors are built to handle real power—year after year—for outstanding service.**

Exclusive cold-setting inorganic cement won't crack, peel, blister or flake. Handles heat shock of frequent on-off operation, without flinching.

Write for Engineering Bulletin 113. Try a Greenohm! Clarostat jobbers stock them. For quantities, let us quote.

CLAROSTAT Controls and Resistors
CLAROSTAT MFG. CO., INC. DOVER, N. H.

ELECTRONICS

Designers

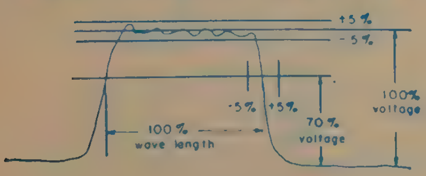
A LINE-
VOLTAGE
STABILIZER

SO SMALL . . .
. . . *it mounts on a radio chassis*

These 15-, 25-, and 50-va G-E voltage-stabilizer units are only a little over 2 inches high and about 9 inches long. They'll mount easily on a medium-sized radio or electronic instrument chassis and will give you an even, non-fluctuating 115 volts for your equipment whether your line voltage is 95 or 130. A special transformer circuit provides a stabilized output voltage within 1% of 115 volts for fixed, unity-power-factor loads.

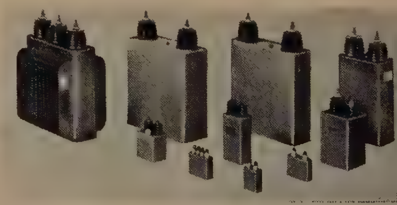
Continuous operation under conditions of short or open circuits will not damage the stabilizer in any way. Since there are no moving parts, there is little maintenance to worry about. For complete information on voltage-stabilizer units of all sizes from 15-va to 5000-va, write for Bulletin GEA-3634.

AN EASY WAY TO PRODUCE SQUARE WAVES



Specially designed G-E Type-E networks will produce impulses which have definite, known energy contents and durations, and thus are ideal for converting a-c or d-c charging voltages into approximately rectangular square waves. These networks consist of capacitor and coil sections adjusted to close tolerances and hermetically sealed in single metal containers.

G.E. helped meet wartime radar demands with thousands of these units and now offers them for commercial use. They are available in a wide range of designs, impedances, ratings, and sizes for pul lengths of 0.1 to 40 microseconds. S Bulletin GEA-4996.

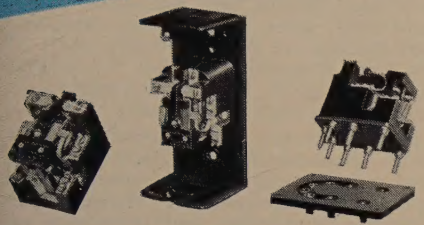


GENERAL ELECTRIC

667-3

Digest

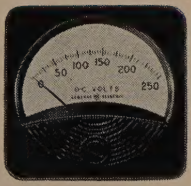
TIMELY HIGHLIGHTS ON G-E COMPONENTS



HEAVY-DUTY RELAYS THAT MOUNT 3 WAYS

This versatile, general-purpose, heavy-duty, a-c relay unit is available in three mounting arrangements: front connected, back connected, or plug-in connected. All three mounting types are available in open or enclosed models and are furnished in spst, dpst, or dpdt circuits. Heavy, long-lasting silver contacts carry 10 amps continuous. Normally-open forms make or break 45 amps; normally-closed forms make or break 20 amps. Relay coils come in 12-, 24-, 115-, or 230-volt, 60-cycle a-c sizes. D-c units are available in similar models. For full details see GEC-257.

ACCURATE BUT RUGGED

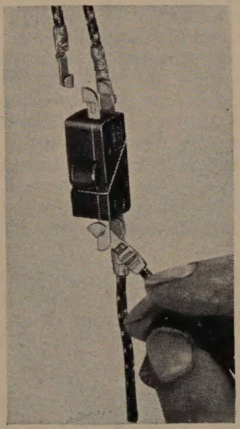


The new, modern-looking, easy-to-read 2½ inch G-E instrument line is improved inside as well as outside. A single, self-contained mechanism supported on an extremely strong Alnico magnet assures permanent alignment even under the most adverse operating conditions. This high-gauss Alnico magnet permits the use of a large air gap with a consequent smoother, non-sticking action. The greater torque-to-weight ratio means better damping and allows the use of heavier vibration-resisting pivots. Accuracy is 5% of full scale on rectifier types, 2% on all others. For complete details, send for Bulletin GEC-368.

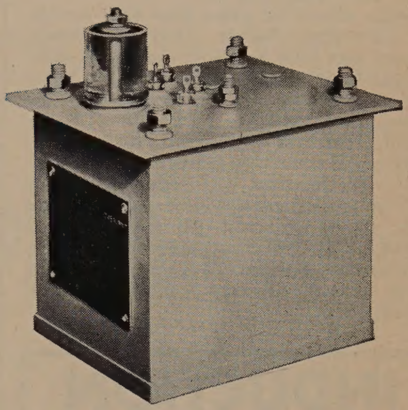
SNAP-SWITCH INSTALLATION TIME CUT TO SECONDS

You'll have a firm electrical connection without the use of solder a few seconds after you begin to install this small but rugged Switchette. Only 1½ inches long and weighing only 9 grams, this 230-vac, 10-amp unit has solderless knife-contact terminals made of pure, tinned copper.

G-E Switchettes are available in a variety of forms and circuits, all of which have double-break contact structures. They're particularly well suited for electronic applications because of their low RF noise output (short contact-bounce).



For your convenience there are screw-terminal and soldering-lug types as well as this special quick-connect unit. Send for Bulletin GEA-4888.



A SMALL PACKAGE OF WELL-REGULATED HIGH VOLTAGE

You get both high voltage and good regulation with small lightweight G-E precision rectifiers. This may interest you if you need compact, well-regulated, high d-c voltage sources for cathode-ray tubes, television camera tubes, radar indicator scopes, electron microscopes, Geiger-Mueller counters, or similar jobs.

These supplies are hermetically sealed and oil-filled. Typical units have outputs of 7 kv at 0.1 ma.—have only 3.5% deviation for every 0.1 ma load and output ripple of less than 1%. Size—only 6″ x 6″ x 7″. Weight—8 lbs. For further data, write: General Electric Company, Section 667-3, Schenectady 5, N. Y., giving complete information on the proposed application with specifications required.

General Electric Company, Section B667-3
Apparatus Department, Schenectady, N. Y.

Please send me the following bulletins:

☐ GEA-3634 Voltage stabilizers
☐ GEA-4888 Switchettes
☐ GEA-4996 Capacitor networks
☐ GEC-257 Heavy-duty relays
☐ GEC-368 Instruments

NAME______________________________

COMPANY______________________________

ADDRESS______________________________

CITY____________________ STATE__________

HOW TO APPLY INDUCTION HEATING

for greater
- *speed*
- *control*
- *efficiency*

HERE are economical methods for heating any metals, alloys or glass that will accept an electrical charge. This new book shows you how to apply the latest techniques for *controlled* mass or zonal heating at temperatures below the melting point, and explains how you can use rapid, low-loss induction heating to melt any conductive material.

Installation and operating data not generally available, and numerous line drawings and photographs—all based on dozens of actual industrial applications—are included to show the wide variety of uses for this type of heating.

INDUCTION HEATING

By N. R. STANSEL

Formerly Engineering Consultant, Industrial Engineering Division, General Electric Co.

212 pages • 6 x 9 • 41 tables
70 illustrations • $3.50

YOU will find this book a well-rounded introduction to modern industrial applications of induction heating, including the design, operation and performance of complete assemblies.

The book's reference value is enhanced by scores of equations, curves, charts, diagrams, and data tables that give you practical guidance for designing, installing and operating modern induction heating assemblies.

You get basic working data on the electric, magnetic and thermal properties of specific materials, on frequencies, and on the influence of dimensions and shapes of the charge.

A few of the applications described—
- Surface-hardening of wheel hubs, journal bearings, flanged bushings, oil-well casings, pump liners, brake cams
- Brazing, soldering, welding metals, alloys
- Degassing electron tubes
- Joining glass to metal
- Forging, hardening, tempering, melting

SEE THIS BOOK 10 DAYS FREE

McGRAW-HILL

McGraw-Hill Book Co., Inc.
330 W. 42nd St., N. Y. C. 18

Send me Stansel's **INDUCTION HEATING** for 10 days' free examination on approval. In 10 days I will remit $3.50 plus a few cents for delivery, or return book. (We pay for delivery if you remit with this coupon; same return privilege.)

Name ....
Address ....
City .... Zone .... State ....
Company ....
Position GE-10-49

This offer applies to U. S. only

BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery; none sent on approval.)

THE MATHEMATICAL ANALYSIS OF LOGIC

George Boole—Philosophical Library, New York. 1948. 82 pp. $3.75.

This book, first published a century ago and now reprinted for the first time, prepared the way for the formal study of the foundations of pure mathematics, which has since become a leading interest of the most advanced schools of philosophers and mathematicians. It considers the laws underlying our mental processes, whereby we state propositions and establish their truth or falsity by means of words, symbols, and logical processes.

The author of this thoughtful book, which may well be called an introduction to the calculus of deductive reasoning, said:

> "It is one fruit of an accomplished labour, that it sets us at liberty to engage in more arduous toils, so it is a necessary result of an advanced state of science, that we are permitted, and even called upon, to proceed to higher problems than those which we before contemplated."

The importance of this remark, and indeed of the whole field opened up by Boole, is highlighted by a recent remark made by Professor Arnold Dresden in a talk expressing the value to engineers of a thorough mathematical training. He said that the first thing to be learned is the importance of order. For example, if we first square A and B and then add them, we get $A^2 + B^2$, whereas if we first add them and then square, we get $(A + B)^2$, something quite different. A man may put on his hat or his coat first with no difference in the results; but if he first puts on his sock and then his shoe, the result will be much better than if he first dons his shoe and then his sock. Throughout life, we should think before we act, rather than act before thinking.

This little book will greatly help the keen student to see beneath the surface, and understand the foundations of things.

P. L. ALGER

ELEMENTS OF ELECTROMAGNETIC WAVES

Lawrence A. Ware—Pitman Publishing Corp., New York. 1949. 203 pp. $3.50.

This book was written as a textbook to give an elementary introduction to electromagnetic theory. It is difficult for the average reviewer to deliver an expert opinion on whether a book will make an excellent textbook, since that depends upon how one teaches the subject. In the opinion of this particular reviewer, it ought to be quite satisfactory for the purpose. The style is highly readable and, although the material is presented in the usual fashion, many additional comments are made that will aid in answering questions which commonly arise.

There are a few comments which might be made on the material. It would seem that perhaps undue stress was laid on the presentation of the curl and its relation to rotation. The treatment of units appears to be rather good but not completely general. This reviewer does not feel that a book of this kind should take sides in favor of one particular system of units, but rather introduce the student to those types which are generally used. In this case the Heaviside-Lorentz system was omitted. Units are really tools, and systems are justified on the basis of their convenience in any particular problem.

In connection with the Poynting Vector, perhaps it should have been pointed out that the interpretation given is in reality an argument which has thus far been justified by results but is not otherwise proved. The reason given for the use of a general curvilinear system does not appear to be quite valid, since reduction to commonly used systems are not all equally easy. At this point it would seem that the student might, with profit, be given the reasons for systems other than the Cartesian.

Finally, in the consideration of wave guides, characteristic impedance was calculated several times. It would seem that an explanation of the reason for choice of any particular impedance, and comments on why they differ, might be of value to a student.

W. C. HAHN

SURFACE ACTIVE AGENTS

Anthony M. Schwartz and James W. Perry—Interscience Publishers, Inc., New York. 1949. 579 pp. $10.00.

This is primarily a semicritical survey and bibliography of the literature pertaining to surface-active agents. It is divided into three parts dealing with the classification and synthesis of surface-active materials, their physical chemistry including both a theoretical treatment of surface chemistry and a practical description of the effects of surface-active agents in various operations, and a description of various processes and products in which the materials play a role. Since most of the literature is scattered in patents and manufacturers' bulletins, gathering it in a book is a useful project.

The book is written in general language. While it is excellent at giving an over-all picture, persons interested in particular phases of the problem will find that the book lacks depth and detail. This is overcome to some extent by the copious use of references to the original literature.

J. R. ELLIOTT

INDUSTRIAL ELECTRICITY: Vol. II—Alternating-current Practice

William H. Timbie and Frank G. Willson—John Wiley & Sons, Inc., New York. 1949. 790 pp. $5.96.

The basic physical theory of operation of alternating-current machinery is here presented for those who do not have a background in mathematics. The entire theory is covered without the use of any higher mathematics than simple trigonometry.

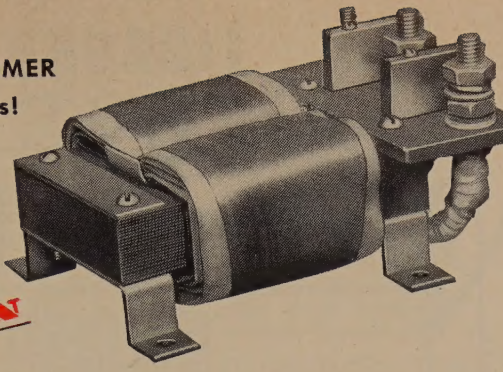
The authors have done a fine job of presenting the physical reasons in basic equations of operations of alternators, transformers, induction motors, synchronous motors, transmission lines, and converters. Each type of machine is thoroughly treated in language that can be understood by the beginner.

A feature of the presentation is a detailed summary at the end of each chapter, serving as a ready reference for a quick refresher of the reader's mind.

The book should be highly useful to those wishing to obtain an introduction to the theory of alternating-current machine operations.

F. O. MACFEE, JR.

IE G. E. FLYWEIGHT TRANSFORMER
livering a full kva from 52 ounces!



A DESIGN TO REMEMBER

an example of the application of

electrical insulating materials

made with

FIBERGLAS* *Yarns*

to help achieve **LIGHT WEIGHT** and **COMPACTNESS** in electrical product design

nsulating materials . . . *made of Fiberglas lass yarns* and silicone . . . contribute to the ight weight and compactness of the amazing G. E. Flyweight transformer.

The Flyweight is the aircraft autotrans-ormer which G. E. engineers designed smaller and lighter . . . *much smaller and approximately two-thirds lighter* . . . than conventional transformers . . . yet which delivers, ounce for ounce, 3 times the kva over a frequency range of 380 to 1,000 cycles!

That *is* a design to remember.

Specifically, glass and silicone insulating materials are used in this design as: *magnet wire insulation, lead wire insulation, layer insulation, laminate, sleeving, and tape. They are all made with space-saving, weight-reducing Fiberglas yarns.*

High thermal conductivity, plus high resistance to moisture, heat, corrosion, and rot are other basic properties of Fiberglas yarns. They, too, offer definite advantages when insulating materials are part of your product's design.

A new manual of Fiberglas-base insulating materials is just off the press. Send for a copy.

Owens-Corning Fiberglas Corporation,
Textile Products Division, Department
919, 16 East 56 Street, New York 22, N.Y.

OWENS-CORNING
FIBERGLAS
T.M. REG. U.S. PAT. OFF.
Yarns

*Fiberglas is the registered trade-mark of Owens-Corning Fiberglas Corporation for a variety of products made of or with glass fibers.

Tempilstiks°

the Crayons that tell temperatures
Tempil-stick
300°

Visit our Booth
No. 525
NATIONAL
METAL SHOW
Cleveland

A simple method of determining safe operating temperatures for:

- **BUS BARS**
- **POWER TUBES**
- **TRANSFORMERS and other electrical equipment.**

also in:

- **MOLDING**
- **CASTING**
- **FORGING**
- **DRAWING**
- **HEAT TREATING**
- **WELDING**
- **FLAME-CUTTING, etc.**

Also available in pellet and liquid form

It's this simple: Select the Tempilstik° for the working temperature you want. Mark your workpiece with it. When the Tempilstik° mark melts, the specified temperature has been reached.

$2 each

gives up to 2000 readings

Available in these temperatures (°F)

113	263	400	950	1500
125	275	450	1000	1550
138	288	500	1050	1600
150	300	550	1100	1650
163	313	600	1150	1700
175	325	650	1200	1750
188	338	700	1250	1800
200	350	750	1300	1850
213	363	800	1350	1900
225	375	850	1400	1950
238	388	900	1450	2000
250				

FREE—While we cannot supply free Tempilstiks°, we will be glad to send you sample Pellets or sample Tempilaq° *(liquid form)* for trial under your actual working conditions. Be sure to state the temperature of interest to you.

Tempil° corp.
134 WEST 22nd STREET
New York 11, N. Y.

LIBRARY NOTES

ON ARTICLES IN OTHER TECHNICAL JOURNALS

ABRASIVES

How to Select Superfinishing Abrasives, by E. L. Hemingway. *Am. Mach.*, July 14, 1949; v. 93, pp. 101-104.

Considering size of grit, hardness of bond, pressure, work speed, lubricant, and material and abrasive hardness.

AIR CONDITIONING

Air-conditioning Design Conditions for Various Industries, by Nathan N. Wolpert. *Heat. & Vent.*, May 1949; v. 46, pp. 70-72.

Compilation of design conditions considered satisfactory for air-conditioned rooms in industry. Data are presented on air control for key processes in many industrial applications.

Modern Thinking Applied to Duct Design, by Kirby Walker. *Heat. Piping & Air Cond.*, May 1949; v. 21, pp. 91-94.

The design and performance of ells for air-conditioning ducts.

DIES

Zinc Alloys for Blanking and Forming Dies, by Gilbert P. Muir. *Tool Engr.*, May 1949; v. 22, pp. 32-33.

Marked economies resulting from the use of temporary dies for sheetmetal working.

ELASTICITY

Transmission of Elastic Pulses in Metal Rods, by D. S. Hughes and others. *Phys. Rev.*, May 15, 1949; v. 75, pp. 1552-1556.

Explains a rapid method of measuring the elastic constants of solids.

FLUID FLOW

Flow of Fluids. *Chem. Engng.*, May 1949; v. 56, pp. 91-138.

To survey those parts of the subject directly allied to chemical engineering, a group of 15 articles is presented.

FORCE AND SHRINKAGE FITS

Assembling Metal Parts by Shrink-fitting, by C. Deschars. *Mat. & Methods*, May 1949; v. 29, pp. 64-67.

How both ferrous and nonferrous mechanical parts often can be assembled more simply, quickly, and economically by shrink-fitting, using liquid nitrogen as the cooling medium.

GAS TURBINES

Flight Propulsion. *Aero. Engng. Rev.*, May 1949; v. 8, pp. 26-38.

Summarizes three I.A.S. papers on aviation gas turbines and jet propulsion.

Fuel Spray Nozzles for Aircraft Gas Turbines. J. A. Bolt and M. F. Saxton. *Auto. Ind.*, May 15, 1949; v. 100, pp. 30-33, 64.

The design and performance of various types of these units are analyzed and discussed by two experts.

LABORATORIES

The Mechanics Laboratory, by Franklin L. Everett. *Jour. Engng. Educ.*, June 1949; v. 39, pp. 579-585.

Should it be a materials-testing laboratory or a place for demonstrating the principles of applied mechanics and strength of materials? Pertains to college laboratories.

LIGHT

Transmission of Light from Diffu Sources by Periscope Tubes, by F. Bundy and H. M. Strong. *Optical Soc. Am. Jour.*, May 1949; v. 39, pp. 393-401

Treats in detail the problem of transmi ting light from a diffuse source, such as flame, to a place some distance away, f the purpose of making spectroscop measurements.

MEASURING INSTRUMENTS

Liquid Iron and Steel Temperatures i Practice, by T. B. Winkler. *Blast Fur. St. Pl.*, May 1949; v. 37, pp. 536-542.

Presents methods and equipment f measuring such temperatures.

Mass Spectrometer for Continuou Gas Analysis, by Jack A. Hunter an others. *Rev. of Sci. Instr.*, May 1949; v. 2 pp. 333-336.

Use of the instrument for recording con tinuously the relative abundance c gases in a three-component mixture.

Noncontacting X-ray Thickness Gage by H. S. Maxwell and C. W. Clapp. *Iron St. Engr.*, May 1949; v. 26, pp. 70-75.

Describes an instrument which gives th operator an opportunity to correct condi tions which may cause off-gage strip whe they occur, thus reducing scrap losses.

PACKAGING MATERIALS

WVP at 0 Deg. by Hygrometric Sweep gas Method, by W. A. Wink and Leonar R. Dearth. *Modern Packaging*, May 1949 v. 22, pp. 134-138, 188, 190, 192.

New apparatus using supersensitive elec tric hygrometers permits high-accurac measurement at low temperatures. Arti cle pertains to tests of water-vapor per meability of packaging materials.

POLARIMETERS AND POLARIME TRY

A Microwave Polarimeter, by Alfred E Schwaneke and Zaboj V. Harvalik. *Rev. o Sci. Instr.*, May 1949; v. 20, pp. 337-341.

Instrument which enables the determi nation of rotation of the plane of polari zation of microwaves in the 3.2-cm band

ROCKETS

Flow Through A Rocket Nozzle Wit and Without Vibrational Equilibrium by S. S. Penner. *Jour. App. Physics*, Ma 1949; v. 20, pp. 445-447.

A procedure is outlined for calculatin the maximum changes in the exhaus velocity of gases which can be introduce during flow through a rocket nozzle a the result of vibrational time lags.

Rocket Chemistry at Inyokern, b Frederick G. Sawyer. *Chem. & Engng. New* July 18, 1949; v. 27, pp. 2067-2069.

A summary of the organization and wor of the Naval Ordnance Test Station a Inyokern, Calif.

SPECTRA

The Spectra of the Heavy Elements, b Frank S. Tomkins. *Optical Soc. of A Jour.*, May 1949; v. 39, pp. 357-363.

Lists the most prominent spectrum line of the elements from protactinium t americium.